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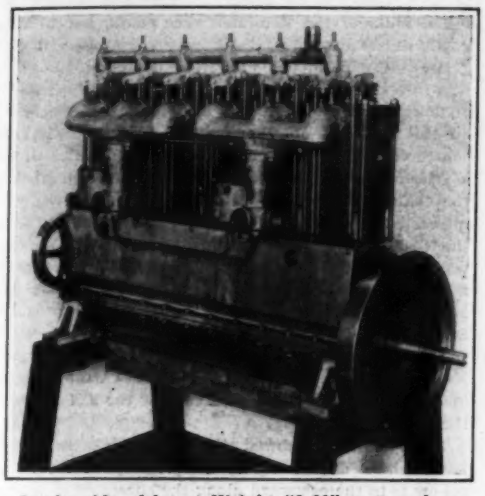
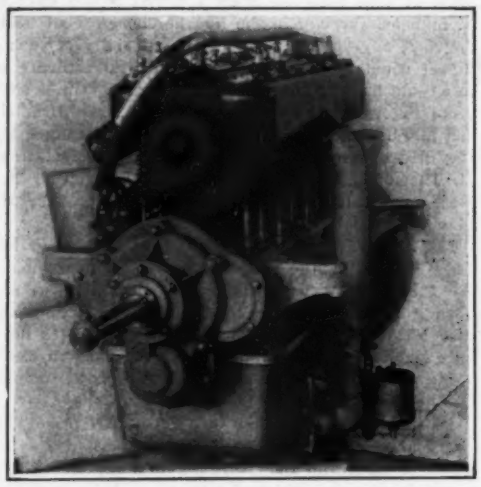
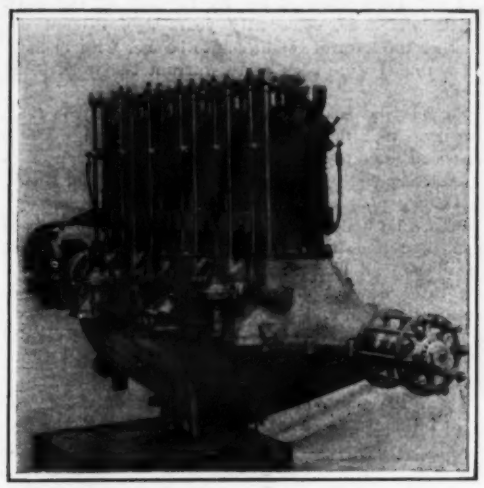


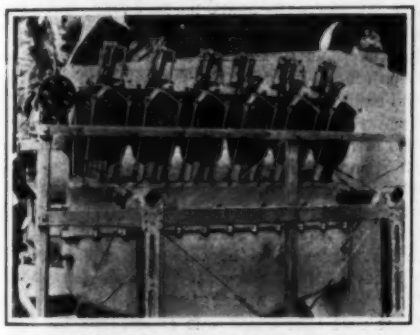
Intake side of latest Wright "6-60" motor, showing carbureters, removable crank-case lid, and general accessibility.



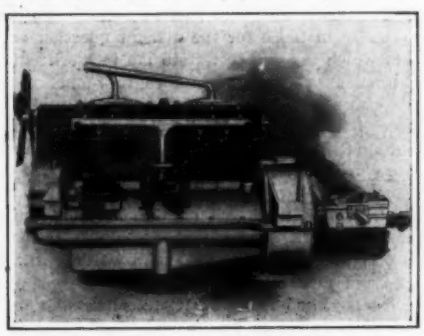
100 h. p. Sturtevant, showing propeller gear housing, reducing from crank shaft speed of 2,000 r.p.m. to 900 r.p.m., a more efficient propeller speed.



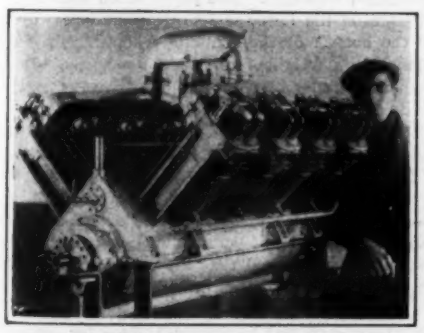
One hundred horse-power Benz. There are two spark plugs in each cylinder. Note general freedom from piping and plumbing paraphernalia.



The 12-cylinder, 100 horse-power Renault aero motor. Air cooled by fan blower.



Speedwell rotary-valve automobile motor, built under the Mead patent.



The new 200 horse-power Curtiss engine, which has two intakes and two exhaust valves in each cylinder.

90 horse-power Austro-Daimler installation in Thomas flying boat. Starting crank enables pilot to start engine without leaving cockpit.

Mead engine, showing silent helical gears and chain driving magneto and electric starter. One rotary valve half withdrawn.

French construction methods. A cylinder at the Gnôme works being bored out from the solid billet.

The Gnôme "artillery." Motors on the testing stands at the Gnôme works in France.

THE INTERNAL COMBUSTION MOTOR IN THE FIELD OF AVIATION.—[See page 24.]

The Channel Tunnel and Its Early History—I*

Plans for Direct Railway Connection Between England and France

By John Clarke Hawkshaw, M.A.

Now that the Channel tunnel question is again under consideration, I feel that it may be of interest to others if I set down some of my recollections of the work which was done, some fifty years ago, to find out whether the natural conditions to be met with in making a tunnel were such as to warrant the work being begun.

No one who has any correct knowledge of the facts can deny that the most useful and practical work to that end was first begun and carried through to a satisfactory end by my father, the late Sir John Hawkshaw.

Before he undertook the work suggestions had been made and lines for tunnels had been laid down, but these were all based on conjecture, for no one could say through what material such tunnels would pass beneath the sea, and without that knowledge the opinion of an engineer as to the prospects of success in carrying through such a work would be of little value, and any estimate of the cost would be worthless.

I am the only one now remaining of those who were intimately associated with my father in the systematic investigation which he began in the year 1865, and which, when it was concluded, led to the formation of the Channel Tunnel Company, of which Lord Richard Grosvenor was the chairman. I attended meetings in this country and in France, was present at all the trials of machinery for excavating and transporting the chalk, and took part in the calculations, more especially in those for the difficult question of ventilation, which my father left to me to work out. I had had much practical experience in tunnel work. For five years I spent some days every fortnight in going through the Severn tunnel works—a submarine tunnel four and a quarter miles long—and I discussed every detail of this work with my old friend, the late Mr. Thomas Andrew Walker, the contractor. I was also familiar with the work on the Brighton intercepting sewer—a work of my father's—which tested beyond all others our power to deal with water in the chalk.

I have given time to the study of geology since I was a boy, and know the chalk cliffs well in France, and from Dover to Folkestone, where I have worked with a pick and shovel collecting fossils with Griffiths, formerly a well-known dealer in them at Folkestone.

I hope you will pardon these personal remarks, but it is well my hearers should know that I do not come before them without some experience of the subject of which I treat.

It was M. Thomé de Gamond who first, by long and patient study of the geology of the Straits, tried to show that a submarine tunnel could be made between England and France. This careful study was the first step taken in the right direction. Unfortunately he gave no attention, as my father did, to the question of what was the most favorable stratum for tunneling operations—the chalk. He seems to have assumed that the chalk was denuded in the Channel, and so he occupied himself solely with a careful survey of the oolitic strata west of Dover. These beds could be well studied in France in the neighborhood of the Straits, and he obtained some fragments of rock from the summit of the Varne shoal, which he correlated with the beds near the French coast. Unfortunately the oolitic beds do not appear on the English coast, and he had to go as far as Oxfordshire to study them in England. He assumed their position under the Channel from his observations made in Oxfordshire and in France, checked to some extent by his fragments from the Varne. It is obvious that any section under the Channel formed on such data must be purely conjectural, and no one knew this better, or was more ready to acknowledge it, than M. Thomé de Gamond, who relied on future borings being taken. He laid down his line of tunnel from Eastwear Bay, east of Folkestone, to Cape Grisnez, hoping to keep in certain beds in the oolite under the sea. He proposed to make some thirteen islands in the Channel, so as to begin the tunnel at many points by sinking shafts in them.

After my father's inquiry was completed, M. Thomé de Gamond abandoned his own plan and become a member of the committee which adopted my father's.

Sir Francis Fox lately stated at a public meeting that Stephenson, Locke, and Brunel approved of M. Thomé de Gamond's line. If they did so without very wide qualification, they, for once, forgot that caution which is inseparable from all engineering eminence, and gave an opinion with an insufficient knowledge of facts. Neither M. Thomé de Gamond nor anyone else could at that time tell what material would have to be tunneled through in the line he chose. That being the case, any opinion as to the practicability of such a tunnel could be of little worth, and no estimate of cost could have any approach to accuracy. Other engineers followed M. Thomé de Gamond: Mr. Brunlees and Mr. Low were advocates for a Channel tunnel, but they had no more detailed knowledge of the facts than M. Thomé de Gamond, if as much, though they had more practical knowledge of work underground, Mr. Low being a mining engineer.

For some years before 1865 Sir John Hawkshaw had been considering the practicability of a tunnel under the Channel, but with his sound common sense, and with a modesty for which all who knew him would give him credit, he did not in any way try to influence public opinion, knowing that the facts to hand were quite insufficient to warrant any proper opinion as to the absence of risk of failure.

In 1865 he began, at his own expense, a private inquiry untrammeled by promoters or associates, to acquire as accurate knowledge as was possible of the nature of the material under the sea. A knowledge of this was the key to the problem. The facts which he collected, after several years' work, as to the nature of the bed of the Channel and what lay beneath it, not only enabled him to form an opinion himself, but they first gave the Channel tunnel question a solid basis. From that time on, the possibilities of making a Channel tunnel and its probable cost could be profitably discussed by practical engineers.

I will now proceed to describe the nature of the inquiry which Sir John Hawkshaw thought necessary before venturing to give an opinion.

First, it was necessary to know in detail the kind of material to be met with on the English and French shores of the Channel.

The geology of the coasts was fairly well known, but it was necessary to study the strata also from an engineering point of view—to make sure that identical beds were found on the two sides of the Channel, to note what facilities the strata offered for tunneling work, and the risk to which they would give rise if they allowed of a too free passage of water.

Early in 1865 Sir John obtained the services of Mr. Hartsinck Day, who, besides being a competent geologist, had also a knowledge of surveying.

Mr. Day's attention was directed principally to the cretaceous beds which Sir John's large experience in tunnel work led him to choose as the most promising material through which to tunnel.

Mr. Day spent several months, in 1865, in examining and surveying the cretaceous and adjacent beds on the coast in England and France, and prepared a geological map showing their position on both sides of the Channel, and he also made a map based on conjecture as to the position of the beds under the sea. (See plan.)

A glance at a map of the Channel will show that the narrowest part lies between the Foreland (near Dover) and Sangatte. A tunnel between those places would be the shortest that could be made, but could it be kept wholly in the chalk?

The cliffs of the Foreland were chalk, but to what depth did it extend? Chalk was not visible at Sangatte. At what depth was it to be found, and what was its thickness? To answer these questions Sir John Hawkshaw determined to bore through the chalk on the English and French coasts. The well-known contractors, Mr. Thomas Brassey and Mr. George Wythes, and Mr. Easton, who had done much work in the chalk in search of water for town supplies, were interested in my father's inquiry, and offered to share the cost of these deep borings, which in those days were more costly to carry out than they would be now. The points selected for the borings were St. Margaret's Bay in England, distant four miles east of Dover and about eight miles east of the outcrop of the lowest beds of chalk on the coast, and Ferme Mouroi in France, two and a half miles west of Calais and four miles east of the outcrop of the same beds on the French coast.

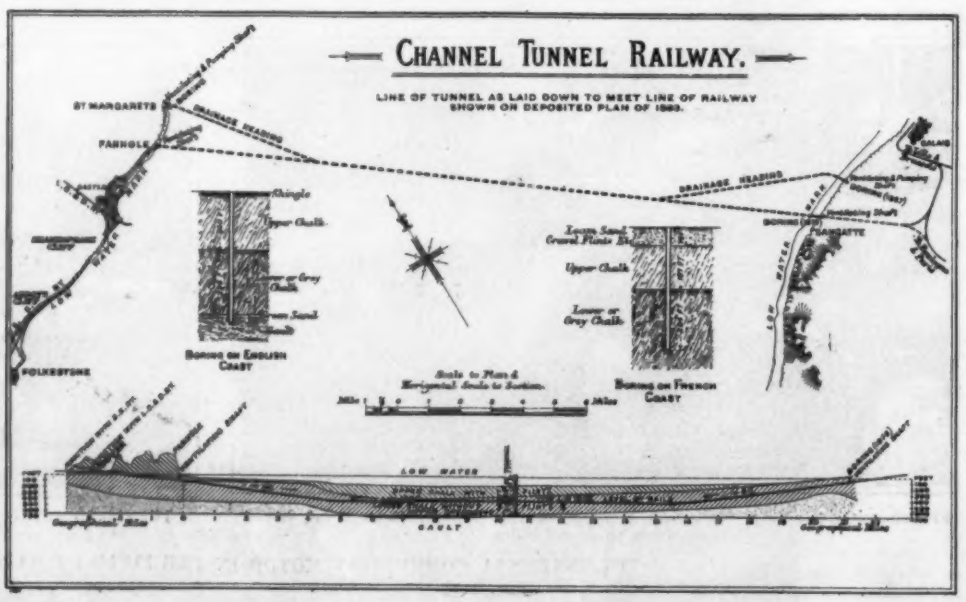
These borings showed that the thickness of the lower chalk does not diminish to any extent as we follow it to the eastward along the coast.

That the chalk extended under the Channel no one now doubted.

The all-important and last remaining point to be settled was, would the chalk be found in the Channel on the surface, or at some depth below it covered by superficial deposits? To ascertain this and check Mr. Day's conjectural plan of the geology of the sea-bed, Sir John employed Mr. H. M. Brunel, one of his pupils, who was still at work in his office. In the years 1865 and 1866 Mr. Brunel carried out a marine survey from a small steamer hired for the purpose, taking advantage of any favorable weather by day or by night. The position of each sounding made at night was fixed by taking angles from the stars. The greatest credit is due to Mr. Brunel for the careful way in which he did this survey, and the accuracy with which he worked out the observations fixing his positions. He soon found out that bare chalk was exposed on the bed of the Channel. An ingenious form of sounding-lead was devised. Round a piece of wrought-iron pipe a heavy sounding-lead was cast. The pipe, which had a sharp chisel edge on the lower end projecting some way out below the bottom of the sounding-lead, was driven by the descending weight into the sea-bed, and brought up a small cylinder of chalk or gault clay, often some inches in length.

As the lower beds of chalk differ in appearance and composition from the upper beds, and more markedly from the gault clay and upper greensand, it was possible to map the position of the chalk on the bed of the sea, and, to some extent, its line of junction with the underlying beds of gault and greensand to the westward. It was found that the outcrop of the gault lay further to the west than Mr. Day had shown.

By 1867 Sir John had got all the information he thought necessary, and he prepared plans for an Anglo-French committee, in conjunction with Mr. Brunlees,



* Paper read before the Royal Society of Arts, and published in its *Journal*.

Mr. Low, and M. Thomé de Gamond, showing a tunnel through the chalk from St. Margaret's Bay in England, to Ferme Mouron in France.

In 1868 the Anglo-French committee applied for a concession from the French government. This led to a long correspondence between the two governments.

After four year's existence as a committee, the English Channel Tunnel Company was incorporated in 1872. This originated the French company, and my father supplied the plans on which their concession was obtained in 1875. By it they were bound to spend $400,000 in preparatory works of all sorts, such as investigations, pits, galleries, borings, etc. The conduct of these operations was intrusted to Mr. Lavalley, so well known in connection with the Suez Canal works. The geological work was assigned to MM. Potier and Lapparent, mining engineers and able geologists, and they were assisted by M. Larrouse, hydrographer to the French navy. They began by repeating, and extending on a more elaborate scale, the marine survey made ten years before by Sir John Hawkshaw. Using a sounding apparatus of the kind already mentioned, they succeeded in bringing up a great number of specimens of the rocks forming the sea-bed. These soundings confirmed, in all material points, Brunel's survey made ten years before. Furthermore, owing to the great number of soundings that were taken, and to the number of specimens from the bottom that could be identified, it became possible to plot with some accuracy the junction of the lower chalk and gault from shore to shore, except for a short distance where these beds pass beneath the sands of the Varne. A second boring was made at Sangatte, and the results of this work, done in 1875-76, were published in 1875-77 in the form of reports, with maps and sections.

The researches by the French company brought no very novel facts to light, such as to disturb the main conclusions which had been already arrived at in this country as the result of my father's work, but they made our knowledge more definite in several particulars. Mr. Topley, of the Geological Survey of England, reported to the Channel Tunnel Company in 1878, and advised that the outcrops of the gault, as shown by the French engineers, might be taken, for all practical purposes, as accurate.

In the year 1882 the Channel Tunnel Company sought to obtain parliamentary powers, and deposited plans showing the line of railway on the English side to join a tunnel from Fan Hole to Sangatte 20.8 miles long under the sea. (See plan.) This tunnel ended in Dover, just behind the castle, with the mouth of the tunnel facing the fort, the guns of which could be pointed into it. It appeared to me that this was a very safe place for the tunnel to enter England, but the military authorities thought otherwise. Before the plan was deposited it was submitted to them, and the War Office appointed some of its officers to visit Dover and approve or not the proposed exit of the tunnel. For some reason my father was unable to be present, and I had to act as guide to the deputation. I only remember two of them, Sir Archibald Alison and Sir Andrew Clarke. I was much disappointed when the outlet was condemned, and I well remember Sir Andrew Clarke saying it would be contrary to all precedent to have an opening from without inside a fortress. I had to set to work at once to find another outlet, which I fortunately did in the valley of the Dour, not far above Dover, so that little was added to the length of the tunnel. A new survey was made, and a parliamentary plan was deposited with the new outlet.

In the same year (1882) the South-Eastern Railway Company sought for parliamentary powers. The chairman of the South-Eastern Railway Company had determined that the Channel tunnel should be a South-Eastern affair. To this my father, who was consulting engineer to that company, had strongly objected. He thought a Channel tunnel ought not to be a one-company affair, and so strongly demurred to the course taken by the railway company that he withdrew from the post he had held for so many years as their consulting engineer.

The plan put forward by the Channel Tunnel Company was a complete scheme, while that put forward by the South-Eastern Railway Company was anything but complete. If Sir Edward Watkin, the chairman, had a definite proposal he did not disclose it. The railway company were tunneling in the grey chalk at Shakespeare Cliff, but in what direction the tunnel would go or how it was proposed to drain or ventilate it, no one knew.

On the other hand, every detail for the completion of the Channel Tunnel Company's work had been considered. Their tunnel was to go in a straight line between Fan Hole and Sangatte, with an exit near Dover, where a junction could be made with the railways of the South-Eastern and Chatham and Dover companies. It was to be provided with drainage headings to drain the tunnel by gravitation from the highest point in the center of the Channel to pumping shafts on the two shores, the positions of which were fixed.

I have just read an article in the *Revue de Deux Mondes* by M. Sartiaux, which seems to indicate that it is now proposed again to put forward the line prepared by Sir E. Watkin from Shakespeare Cliff, and to endeavor to keep the tunnel in the lowest beds of the chalk, not in a straight line or with regular gradients, but following the grey chalk in all its sinuosities. A drainage heading is to be made on a line fixed provisionally, but which may be varied by the knowledge of the strata gained from weekly borings, which will also determine the direction of the main tunnels, and consequently their length and cost. The drainage heading will meet the main tunnels at a point near the middle of the Straits, from which the main tunnels will rise, and the drainage heading will fall toward the shore. They will also diverge from this point so as to keep in the same bed of chalk, which is deeper down as we go up the Channel. Cross adits will be driven from the drainage heading to the main tunnels as their direction is determined by the borings.

Now the making of numerous borings is what a hydraulic engineer would do if he wanted to strike fissures in the chalk to get a water supply. The more borings made the more water he would hope to get, and would most likely not be disappointed.

The grey chalk is not free from water, as we know it on land, and to a certain extent under the sea. I saw many small runs of water in the French works, to which I shall refer later on.

In my early engineering work I had some experience of the evil results of borings, on works in progress close on fifty years ago. I was in charge of the construction of the Albert Dock, which was being made for the Hull Dock Company. We had to build a long lock 80 feet wide, on what appeared to be a perfect foundation of about 40 feet of boulder clay, nearly as hard as rock, and quite impervious to water. When the excavations for the lock had nearly reached their ultimate level we were suddenly drowned out one night by an outburst of water in the excavation. Where the water came from it was impossible to say. More pumps were put up and the area excavated was divided into many small compartments by sheet piling. In the meantime the ground settled in and around the excavation, showing that the water was bringing up material from below. In time we were able to free some of the compartments from water. In one of them, on a clean surface of dark boulder clay, I saw a small hole about 2 inches in diameter full of small grains of white chalk and sand. It was evidently a bore hole, one of many which had been made by rival promoters before the bill for the dock was passed. In the night a jet of water burst up through the bore hole, bringing with it large quantities of clean yellow sand from a bed on the surface of the chalk. This we proved by making a fresh boring through the boulder clay to the chalk. More than one of these borings was no doubt discharging water into the works, and the site had to be abandoned and the dock made shorter to provide a new site for the lock. This incident shows what trouble a few 2-inch borings may bring about in the neighborhood of water-bearing strata.

No doubt extraordinary precautions would be taken in making the proposed borings referred to by M. Sartiaux. But to make a number of borings beneath the sea is to take quite an uncalled for risk. If control of one boring in a tunnel were lost, and the sea-water tapped, the work might have to be abandoned.

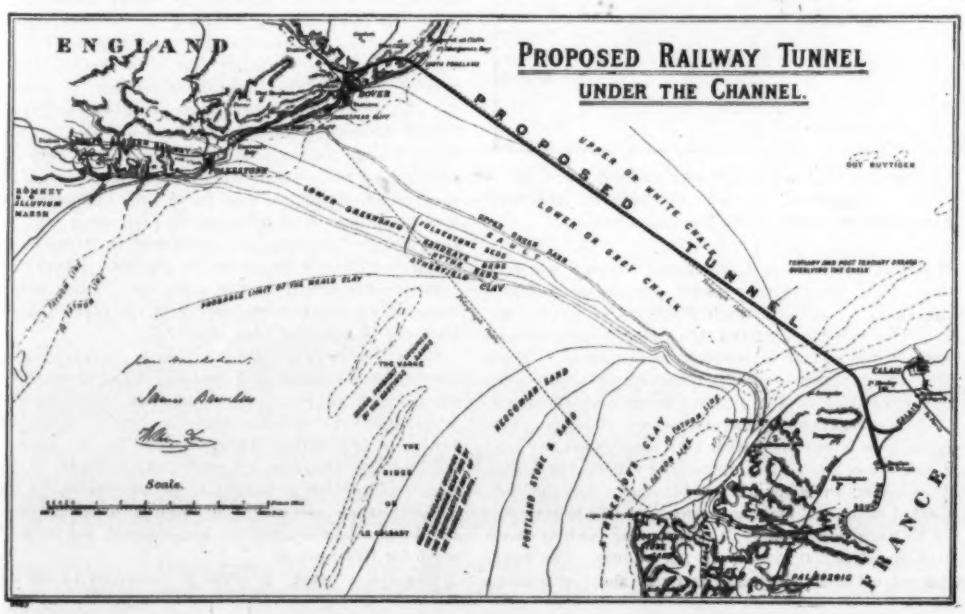
Where the chalk is 500 feet thick to the east of the outcrop, no borings outside the finished work would be necessary, and with six miles less of tunnels to make the risk of meeting water would diminish.

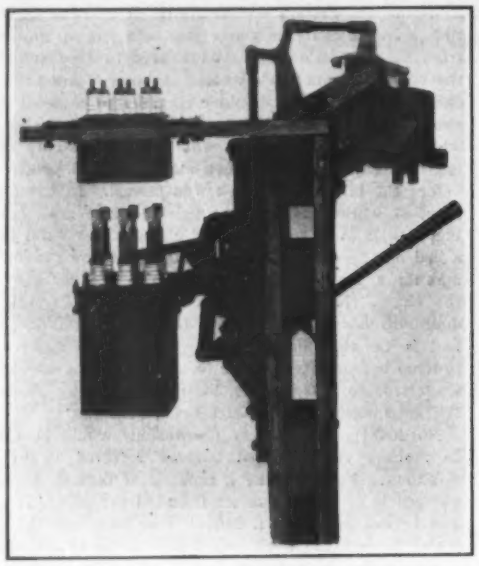
In settling the line for the tunnel we have to consider on what line will an error in our geological calculations be of least moment in our tunneling operations. The French company's marine and geological survey was made with care and precautions such as were probably never before taken. As long as it deals with the surface of the sea-bottom the reports and accompanying plans and sections probably tell us a true story on which we may rely. But when we pass from the surface of the sea-bed to the strata beneath we go from facts to conjectures. A longitudinal section down the center of the Channel shows the chalk from where it begins, at the outcrop of the gault, dipping at first rapidly beneath the sea, the dip gradually diminishing as we go eastward. Now the part of the section in which error is most likely to be found is in the curve which denotes the base of the chalk near the outcrop. For the curve showing the base of the chalk depends not only on the position of the line on the map, which shows the junction of the chalk and the gault, which is probably in the main correctly plotted, but also on the line which shows the junction of the two lowest beds of chalk of the French geologists (Craie de Rouen and Craie de Moyenne). It would be very rash to take this last line as other than approximate; yet all it could tell us, if it were correctly plotted, would be the dip of the base of the chalk close to the sea-bed; and even to get at that we should have to assume the thickness of the Craie de Rouen from its ascertained thickness on the two coasts. Of the dip a short distance below the sea-bed we really know nothing, and the curve indicating it must be imaginary. If the tunnel is to follow the lower beds of chalk it will have to be near this curved line, and any variations in the curve will necessitate deviations in the line of the tunnel, so that its length might be largely increased. This continual deviation would add largely to the difficulties of construction. Again, the lower the beds in which the tunnel is placed, and the nearer to the outcrop of those beds, the greater will be the risk of water finding its way along the planes of bedding from the outcrop.

As we pass from the outcrop of the chalk and the gault in an easterly direction along the Channel, the chalk increases in thickness. On the Fan Hole-Sangatte line it is 480 feet thick, double the thickness it is on the Shakespeare Cliff line. This was conclusively proved by the borings made by my father. An error which would necessitate a considerable deviation in the Shakespeare Cliff line of tunnel would not affect that on the Fan Hole-Sangatte line, where there is the ample margin for error of 250 vertical feet.

The only reason which has been given for taking the tunnel under the shore line to the west of Dover is, that by so doing it is supposed that it can be made wholly in the lowest or grey beds of chalk. It is asserted that no water, or very little, will be found in these lower beds. Now what are the facts? We are told that little water was found in the heading from Shakespeare Cliff. I cannot speak from personal knowledge as I did not visit that work. In the headings driven at Sangatte, in the corresponding beds in France, water was met with flowing from fissures at the sides and bottom, and not confined to one place, but throughout the headings. The quantity which I saw was not large, the largest spring, perhaps, thirty gallons a minute, but it was enough to prove that those beds are not impermeable.

(To be continued.)

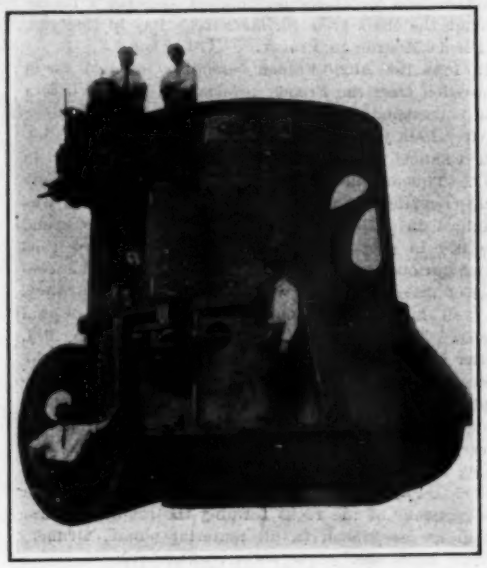




Triple pole, single-throw, 2,500-volt, 300-ampere oil switch with solenoid operating mechanism and disconnecting device.

Gatun Hydroelectric Development for the Panama Canal

How the Surplus Water of Gatun Lake will Furnish Light and Power for the Panama Canal and Railway



Thirty-six hundred horse-power Francis turbine for the Panama Canal hydroelectric station at Gatun spillway.

THE permanent supply of electric energy for the Panama Canal is generated in the Gatun hydroelectric station, which is located at the Gatun spillway dam. The tremendous water storage in the artificial Gatun Lake, fed by the Chagres River, not only carries vessels the greater part of the way across the Isthmus on a level about 85 feet above the oceans, and provides water for raising and lowering them gently through the Gatun, Pedro Miguel and Miraflores locks, but it also has afforded an excellent opportunity to generate electric current for lighting the canal, for operating the gigantic gates and other locking machinery, and for the locomotives towing ships through the locks.

Electric current will likewise be used for coal handling plants at both ends of the canal, for machine shops, waterworks, drydocks, and possibly in the future for hauling trains on the Panama Railroad. To insure continuity of service in case of accident, a steam-electric station at Miraflores, erected a few years ago to supply power for construction work, will be ready to pick up the load when necessary.

BRIEF DATA ON THE CANAL.

The extreme length of the canal is about 50 miles, it has a minimum depth of 41 feet, and the channel varies from 300 to 1,000 feet wide. The famous Culebra cut has a length of about nine miles. The crest of Gatun dam has a length of 8,000 feet and an extreme width of 2,100 feet, the height above the normal lake level being 30 feet. There are three double sets of locks at Gatun, one double set at Pedro Miguel and two double sets at Miraflores. The average lift of each set is 28½ feet, the length of each chamber being 1,000 feet and the width 110 feet. The time required for the passage of vessels through the locks is about three hours, and through the canal from ocean to ocean eight to ten hours.

The width of the Canal Zone is 10 miles, and it has an area of 436 square miles. More than 40,000 men have been employed in building the canal, and over 200,000,000 cubic yards of earth have been excavated. It is estimated that $375,000,000 will represent the total cost of this mammoth project.

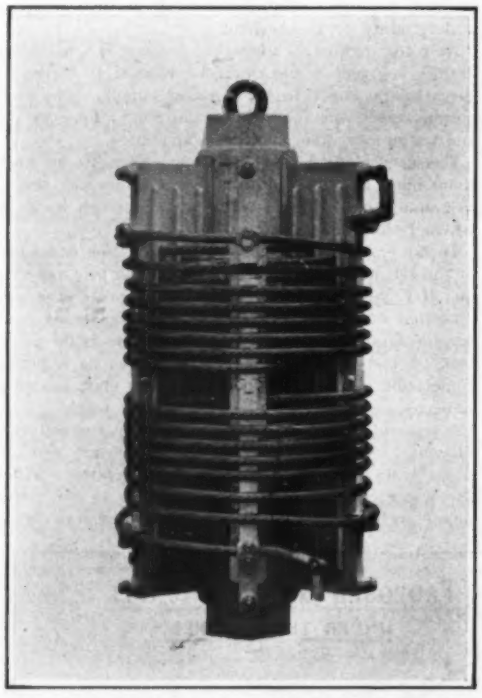
POWER AND DISTRIBUTION EQUIPMENT.

The complete equipment for the power and distribution system on the canal comprises the 7,500 kilowatt, 2,200-volt hydroelectric power plant at Gatun; the 4,500-kilowatt, 2,200-volt Curtis turbo-generator electric power plant at Miraflores for emergency; a double 44,000-volt transmission line across the Isthmus, connecting Cristobal and Balboa with the two power plants; four 44,000-2,200-volt substations, stepping down at Cristobal and Balboa, and up or down at Gatun and Miraflores, depending on which of the two plants is supplying power; thirty-six 2,200-240-volt transmission stations for power, traction and light at Gatun, Pedro Miguel, and Miraflores locks; three 2,200-220-110-volt transformer stations for the control boards at the locks; and stations at Cristobal and Balboa for the coal-handling plants, machine shops and drydocks.

The Gatun hydroelectric station has a capacity of 6,000 kilowatts, and provision has been made to increase this to an ultimate capacity of 12,000 kilowatts, should this amount of power be required later for the operation of the Panama Railroad, the three outlet pipes in the dam having been installed along with the original pipe lines.

OPERATING HEAD AND INTAKE.

The gross head available from Lake Gatun to mean tide level of the Pacific Ocean varies from a maximum of 91 feet in the extreme flood times to a minimum of 79 feet, to which level the lake may possibly drop toward the close of the dry season. The plant is designed consequently to develop the full water output when operating under an effective head of 75 feet. For three or four months of every year there is absolutely no rainfall on the Isthmus; and during this period, it is desirable to conserve the water to as great an extent as possible. Maximum efficiency was, therefore, demanded for the apparatus of both the waterwheel and generator manufacturers.



Current limiting reactance with concrete core, 25-cycle, 42-kilowatt, 64-volt, 656-ampere, Gatun hydroelectric installation, Panama Canal.

Water is taken from Lake Gatun through passages 12 feet wide, fitted with wrought iron racks 29 feet 7 inches high to prevent trash from entering the pipe lines. The water is admitted into the pipe lines through three 10-foot 6-inch diameter head gates. These gates are of massive cast-iron construction, the seats where water tightness is required being made of bronze.

DETAILS AND OPERATION OF THE GATES.

Each gate is equipped with two steel stems for raising and lowering. These stems are fitted with bronze nuts working in roller thrust bearings, and the nuts are fitted with steel bevel gears arranged to be operated by a 15 horse-power, 220-volt, alternating current motor with a speed of 750 revolutions per minute. The motor is placed between the stems and has shaft extensions on each side that carry two bevel pinions arranged to engage the bevel gears on the stem nuts. The stands which carry the stem nuts are equipped with hand operating mechanism, arranged to be disconnected when the gate is operated electrically.

The gates are equipped with automatic control devices, consisting of a limit switch geared to one of the gate stems and a float switch actuated by the water in the pipe. The action of the control is as follows: The gate being closed and the pipe line empty, the gate motor switch is closed at the power house, which starts the motor and begins opening the gate. When the gate has opened a sufficient distance to fill the pipe line in about five minutes, the limit switch opens the circuit and stops the motor.

The gate remains in this position until the pipe line is filled and the water rises in the 36-inch diameter air vent just below the gate, when it actuates a float switch and again closes the motor circuit, thereby causing the gate to be opened fully, when the limit switch again operates to prevent over-travel. The gate is closed by reversing the main switch at the power house, which causes the motor to operate, the limit switch again stopping the motor when the gate has reached the closed position. In case the electric power should fail, the gates can be hand-operated by two men.

THE INTAKE PIPE LINES.

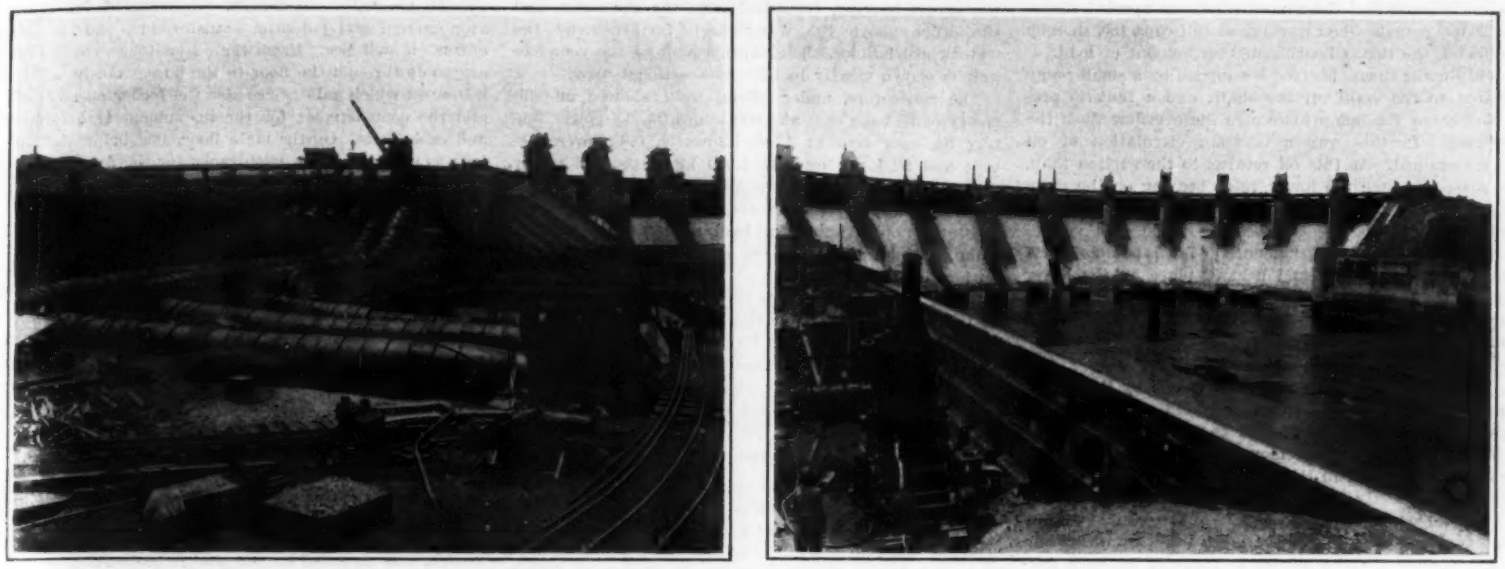
Each of these gates is bolted to a pipe line 10 feet 6 inches in diameter with an average length of 420 feet. The pipe lines are made of ⅜-inch steel plates in courses 8 feet long, each course being made of three sheets to form the circumference. The center of each course is fitted with a 3-inch by ⅝-inch Z bar ring, which is also made in three sections. After the pipe was riveted together at the plant, the outside was covered with a layer of reinforced concrete to prevent rust.

The pipe lines are led down to the rear of the power house on a uniform slope from the spillway, and are connected to the turbines in the power house through 90-degree bends having a radius of 70 feet. Each of the pipe lines is arranged for attaching a Pitot tube testing apparatus while its unit is in service, and one pair of portable tubes for taking readings in planes of the pipe at 90 degrees from each other was supplied.

This is accomplished by fitting each pipe with two 6-inch saddle nozzle connections located 45 degrees on each side of the vertical center line of pipe. From these connections there are two Pitot tube supports placed across the pipe at right angles to each other with their thin sections pointing in the direction of the flow of water and fitted with guides for the Pitot tubes. These supports are bolted in the pipes and, while they are intended to remain permanently in the pipe, if desired, they can be removed very readily.

Each 6-inch outlet on the pipe is closed by a gate valve with tongued and grooved flanges that match the base on the Pitot tube apparatus. Each Pitot tube is arranged to measure both the static and velocity heads at practically the same point in the pipe, and readings are obtained by means of "U" tubes containing a colored liquid having a specific gravity of about 1.25. Carbon tetrachloride thinned with gasoline to the proper specific gravity and colored red is usually used for this purpose.

One end of each "U" tube is connected to the static



Panoramic view of the Gatun hydroelectric installation, Panama Canal, under construction, showing pipe lines and turbines erected.

and the other to the velocity side of the Pitot tube, and the difference in height of the colored liquid columns read, from which the velocity of flow in the pipe is calculated. This form of Pitot tube is very simple and reliable, as it does not require compressed air to keep the head within readable limits and, at the same time, the difference between the static and velocity heads is read off directly.

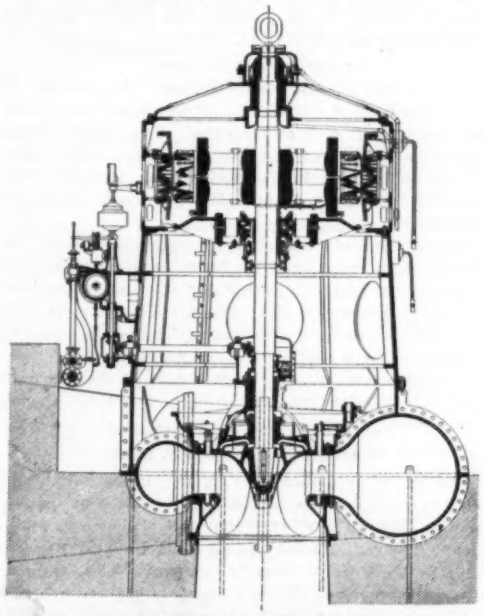
In order to measure the flow in any pipe line, it is only necessary to bolt the Pitot tube base plates to the valve flanges and open the gates, when the tubes can be pushed into the pipes and readings taken. When the test is completed, the Pitot tubes are withdrawn until they clear the gates, then the valves are closed, and the apparatus can be removed.

THE GATUN HYDROELECTRIC STATION BUILDING.

The principal buildings connected with the actual operation of the canal are the hydroelectric station at Gatun spillway; the gate control house at the spillway; the four substations of the transmission system at Gatun, Miraflores, Cristobal and Balboa; and the three-lock control houses. All these structures are designed along simple lines in harmony with the unbroken surfaces of concrete of the adjacent engineering works, and for the same reason are devoid of all modeled ornament; the plain wall surfaces are relieved only by the restrained moldings of the bases and cornices, and architraves bounding the openings. This has the effect of enlarging the scale, or apparent size of the buildings, though they appear dwarfed by their proximity to the large masses of concrete.

The hydroelectric station measures 61 feet by 137 feet and has an extreme height of 74 feet. The building is designed on the unit principle, to admit of future extension, and consists of a single room open to the roof, exposing the trusses upon which is laid the reinforced concrete roof slab, which, in turn, receives the red Spanish tiles. The walls are of poured concrete, 30 inches thick to the level of the crane rails, near the cornice. The exterior overhang of the main roof is 13 feet 2 inches and that of the monitor roof 4 feet 8 inches, the exceedingly large projections having been generally adopted for all the permanent buildings in the zone as a shelter from tropic rains, as well as from the heat of the sun.

Beyond the general use of tile for flooring, and an interior white enameled brick wainscot 14 feet high, to relieve the coarseness of the walls, there is no difference in the finish of the concrete surfaces within and without. The dead surfaces of the concrete or stuccoed walls, which will probably be improved when weathered, are further relieved on the exterior by the red tile roofs. The principal ornamentation is on the underside of the broadly projecting cornice, which is broken up into paneled coffers. A number of these contain light outlets that cast light down on the walls and throw the structure into strong relief at night. The large glass surfaces are attractively broken up into smaller panes. Little wood is used anywhere, but for economy it is utilized in the large side frames and sash, the end frames and sash being of iron.



Cross-section through waterwheel, generator, and exciter, Gatun hydroelectric installation, Panama Canal.

The interior has four principal elevations, namely, a pit for the three 2,500-kilowatt, hydroelectric turbines, a main floor, and two galleries. The turbine pit, with an area of over 2,100 square feet, is located 6 feet below the level of the main floor and is reached by iron stairways descending alongside the turbines. From the pit, other stairs lead down to the storeroom on the north side, and to the air compressor and oil pump compartments at the ends. The pit is lined with white enameled brick, which is both attractive and cleanly. The 14-foot wainscot extends from the main floor up to the first gallery elevation on the south wall of the pit.

Intermediate between the pit and the main floor, and reached by stairs from the latter, are toilets in the southeast corner of the building, giving separate accommodations for white and colored employees. The walls are treated in enameled brick, similar to the turbine pit, and the rooms are equipped with modern fixtures and separate shower compartments.

The main floor divides into two parts, one being partitioned off and devoted to the use of the electrical equipment, and the other forming an uninterrupted passage on the longitudinal axis of the building, terminating with two large entrance doors at either end. Easy access to railway cars is afforded by means of a track which enters this floor from grade through the northwest door, thus giving every facility for handling heavy machinery by the 30-ton electric crane running the length of the building overhead.

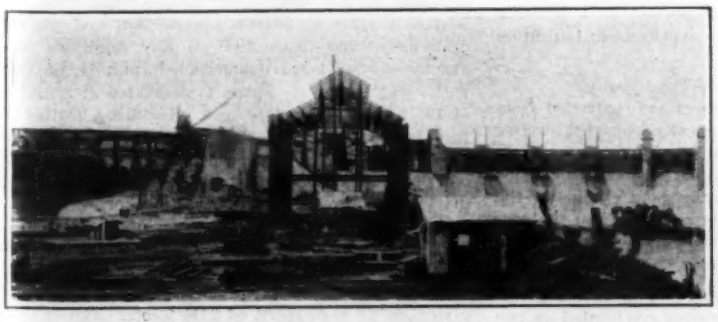
Concrete stairways at either end of the building give access to the mezzanine and second galleries, which are devoted to the switchboards, oil switch compartments, reactance coils and other electrical equipment. Two such galleries extend the entire length of the station on the northeast side, and in the south corner are superimposed two smaller ones used as a machine shop and an office, respectively. The sash in the large side wall windows are operated in sections by a hand-gear system, and the continuous bottom hinged sash in the roof monitor are operated by motors.

THE THREE FRANCIS TURBINES.

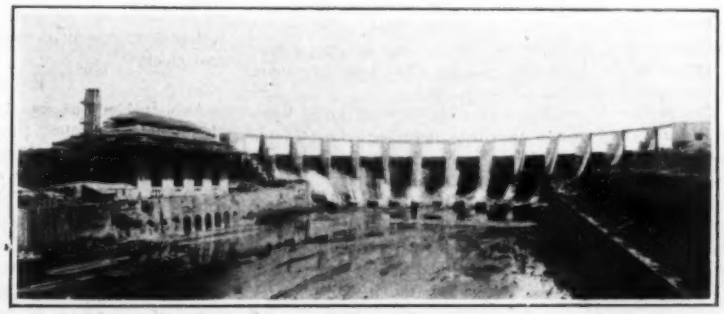
The three 2,000-kilowatt main generating units in the hydroelectric station are each driven by a special 50-inch vertical, single runner, Francis turbine manufactured by the Pelton Water Wheel Company. Each turbine has a maximum capacity of 3,000 horse-power when operating under an effective head of 75 feet, and at a normal turning speed of 250 revolutions per minute. The turbines are located at such a height that the center of the runners is 20 feet above tail water.

The water is discharged through steel-lined concrete draft tubes, which are 71-inch diameter at the discharge from the runners, and increase to an elliptical section of 9 feet by 17 feet at the outlets, which are horizontal, there being a 90-degree bend in the tubes. The linings are made of ¼-inch steel plates, which were fitted together in the shop and shipped knocked down.

The turbines are of the spiral case type and are fitted with heavy cast-iron distance rings which carry the generators. The weight of the revolving parts of each generator and turbine is carried on a roller thrust bearing mounted on top of the generator. The turbine



General view of Gatun hydroelectric station and penstocks, Panama Canal, looking south, spillway in the background, June 27th, 1913.



Gatun spillway dam, looking south from bridge, showing fourteen crest gates, Ogee dam and Baffle piers; hydroelectric station on left.

is so designed that the runner exerts an upward thrust of 20,000 pounds when working at full capacity, thereby relieving the thrust bearing of that amount of load.

Oil for the thrust bearing is supplied by a small pump geared to the main turbine shaft, and a tank is provided below the pump to receive the overflow from the bearing. In this way a constant circulation of oil is maintained. As this oil returns to the suction tank, it passes through the lower guide bearing on the main shaft and lubricates it.

The runners of the turbines are made of a special bronze and weigh approximately 7,000 pounds each. They are bored taper and held in place on the lower end of the shaft by means of bronze nuts. The surfaces of the runner vanes are all hand finished to reduce hydraulic losses.

THE GOVERNORS.

The speed of the turbines is controlled by Pelton oil-pressure governors, which are mounted on the distance rings and are driven by bevel gearing from the main shaft. Tachometers are mounted above the governors on supports bolted to the distance rings. The tachometers are directly connected to the governor heads.

The governors are fitted with small electric motors for varying the speed of the main units for synchronizing purposes, and a device is provided on each governor for varying the permanent drop in speed from no load to full load. This can be adjusted for any variation from 5 per cent drop to absolutely constant speed, from friction load to maximum load. The governors are also fitted with hand control mechanism for adjusting the gates independent of the oil pressure.

The wicket gates for controlling the supply of water to the runner of the turbine are steel castings with hand finished surfaces. Each gate has its pivot stem extended upward through a packing gland and is fitted with an operating lever. All the gate levers are connected to the gate ring by means of bronze links, and the gate ring is connected to the governor rockshaft. All the regulating mechanism is therefore outside the turbine case, except the gates themselves. The water passages on each side of the gates are provided with renewable rolled-steel wearing plates.

The pressure oil for actuating the governors is supplied by two Pelton rotary pumping units, driven by 10 horse-power alternating current motors, at a speed of 375 revolutions per minute, each pump being capable of supplying the governors on all three units. The governors work on an open system, there being no vacuum chambers used. The discharge oil from the governors is led into oil sump tanks, from which it passes into the suction of the pumps. Each oil pump is connected to a steel pressure oil receiver with an air space above the oil. The oil sump tanks and pipe connections are installed in duplicate, and valves are provided to enable one set to be cleaned while the other is in service.

GENERATORS AND DIRECT CONNECTED EXCITERS.

The three main generating units are of the vertical revolving field type, each being provided with a direct-connected exciter. The generators are of the General Electric Company manufacture, and are 3-phase, 25-cycle, with a guaranteed continuous capacity of 2,000 kilowatts at 0.8 power factor, 2,200 volts, 250 revolutions per minute, and with an overload rating of 2,500 kilowatts at 0.8 power factor for 2 hours.

The exciters are of 50-kilowatt capacity at 125 volts, each capable of furnishing exciting current for two generators under maximum guaranteed load. Each unit, generator and exciter, weighs approximately 65 tons.

The generators are carried on heavy cast-iron distance rings furnished by the Pelton Water Wheel Company, the stationary armatures being bolted to these rings. The thrust and upper guide bearing support consists of a very rigid iron casting, bolted to the top of the stationary armature.

The thrust bearings are of the roller type, manufactured by the Standard Roller Bearing Company, Philadelphia. These bearings carry the weight of the complete revolving element, consisting of the generator field, exciter armature and turbine runner, which are mounted in this order on a one-piece shaft. The weight thus suspended is 32 tons. The exciter magnet frame is supported by lugs cast on the stationary armature of the main generator.

The exciter is readily accessible through large holes in the distance ring, a platform being provided inside the ring from which the exciter commutator and generator collector rings may be reached.

Provision is made for securing the magnet frame of the exciter to the revolving element of the generator, so that the complete rotating element, together with the exciter frame, is raised at once in disassembling.

For inspection of the roller bearing, it is necessary simply to remove a speed limiting switch from the top of the shaft and the upper half of the bearing housing. There are two guide bearings, one immediately below the thrust bearing, furnished with the generator, and the other above the waterwheel, furnished by the waterwheel builder. The arrangement of the complete unit is shown clearly in the cross-sectional view.

The generators, under official tests, showed an efficiency of 95.1 per cent at 2,000 kilowatts, 0.8 power factor; 94.3 per cent at 1,500 kilowatts, 0.8 power factor; and 92.5 per cent at 1,000 kilowatts, 0.8 power factor. The guaranteed temperature rises of 40 deg. Cent. above room temperature, of 25 deg. Cent. under continuous operation at full load, and 55 deg. Cent. rise after 2 hours run at 25 per cent overload, were met with an ample margin.

All of the apparatus was subjected to the most rigid and minute inspection during manufacture by representatives of the Isthmian Canal Commission. The insulation of all windings was made moisture-proof on account of the extreme climatic conditions on the Isthmus. The revolving field was given a running test at twice normal speed in the testing pit at the factory provided for this special purpose.

REACTANCES.

Current limiting reactances were provided to give 5 per cent reactive drop, at 2,500 kilowatts, 2,200 volts, 3-phase, 25-cycle. While the generator windings are sufficiently rigid to stand the strain of a short circuit under full load, these reactances will reduce the shock on the windings and will also serve to render the operation of synchronizing the machines easier and safe.

MOTOR-GENERATOR SETS.

In addition to the direct-connected exciters, two motor driven exciters are supplied. These consist of a 100-kilowatt, 125-volt, 500-revolution per minute generator, direct connected to a 150 horse-power, 2,200-volt, 25-cycle squirrel cage type, induction motor. They are mounted on a common base plate and provided with three bearings. These exciters can also be used for charging the control battery.

DISTRIBUTION SCHEME.

On account of the great distance, the current is transmitted at a voltage of 44,000 from the power stations to both ends of the canal. The step-up transformers are, however, not located in the power plants, but in substations in their vicinities; therefore, the power plants generate and distribute only 2,200-volt current.

The system of connection throughout employs the double bus, double switch scheme, with provision for disconnecting any oil switch for cleaning or repairs without interrupting the circuit. This system was naturally selected for this station because it was considered the most flexible for the requirement of uninterrupted service, which the engineers of the Isthmian Canal Commission have so carefully considered, though without superfluous complications.

INSTRUMENT AND CONTROL BOARD.

The main switchboard is of the benchboard type, with vertical rear board for relays, watt-hour meters, graphic instruments, and the control battery equipment. The switchboard and all control apparatus were built by the General Electric Company. The space between the front and the rear boards is inclosed by grille work with doors at both ends, and a metal molding extending along the floor and the top of the board gives a finished appearance to the whole. On the top of the switchboard is a second story, for the electrically-controlled generator and exciter rheostats, accessible by means of a ladder inside the structure. The first panel from the left in the benchboard controls the exciters, the next three the generators, and the remaining four the twenty-four feeder circuits. The system of connection is represented by dummy busses of polished copper on top of the bench. The interior view of the benchboard shows the arrangement of operating busses and fuses, potential busses, instrument resistances, and the channel iron risers with distributing tubes, which carry the instrument and control leads to their points of connection on the board.

A generator voltage regulator, transferable to either of the two sets of busses, is installed on a separate pedestal, which also carries the synchronism indicators and clock.

EXCITER BOARD.

As mentioned above, the exciters are controlled from the benchboard, but the electrically operated exciter switches and field switches are mounted on a separate board located so as to make the exciter connections as short as possible. This arrangement eliminates the exciter busses and the main connections from the control board, but leaves the control of the whole equipment in the hands of the operator.

BUS AND SWITCH COMPARTMENTS.

The bus and switch compartments are located on two galleries. On the upper gallery are located the control board near the end of the station that may be extended, the generator reactances, compartment for generator current and potential transformers, and the generator oil switches. From the oil switches, connections are made through the floor to the busses on the gallery below, on which gallery are also the feeder oil switches, and the compartment for the instrument transformers and cable bells. On the main floor, just below this gallery, is the cable vault with racks for the feeder cables.

All compartments are built of concrete with flame-proof doors. The busses and connections are made of solid copper rods of sufficient size to give a rigid construction even where the current is very small. After installation, the busses and connections and all joints are heavily insulated with varnished cambric to make them perfectly safe.

All the 2,200-volt oil switches are solenoid operated, and are provided with mechanism for disconnecting them easily for cleaning or repairs, so arranged that the live parts are completely covered. For the hand-operated switches, a pipe framework supports vertical metal guides which carry the oil switch operating mechanism and slate base forming a section of the switchboard panel. On the guides a lever and toggle mechanism is mounted, by which the oil switch and slate base may be raised and lowered. Above the oil switch, and mounted on the pipe framework, a stationary cast-iron base carries the disconnecting switch studs and insulators. The high-tension leads run to the tops of the disconnecting switch studs, and the bottom of each stud is equipped with contact fingers. On the top of each oil switch stud is mounted a contact blade.

When the oil switch is raised, these blades engage the contacts on the bottom of the disconnecting switch studs, which thus in the closed position form extensions of the oil switch studs. The disconnecting switch contacts are surrounded by insulating shields which prevent accidental contact. When the oil switch is lowered, it is completely isolated from the circuit. When the oil switch is raised, it always goes to a fixed height, where it is latched. An interlock prevents the oil switch from being raised or lowered unless its contacts are open, precluding the circuit being closed or opened by the disconnecting switch. In some instances another interlock makes two single-throw switches a double-throw switch and prevents both switches being closed at the same time.

For solenoid-operated switches, the same form of disconnecting switch is used; but the solenoid is stationary, and the connecting mechanism to the oil switch has a vertical slotted link that allows the oil switch to be raised and lowered without being disconnected from the solenoid mechanism. A mechanical interlock prevents raising or lowering an oil switch while in the closed position.

The complete hydraulic equipment for this installation, including the racks, headgates, pipe lines, Pitot tube-testing apparatus, turbines, governors, and oil pumping units, was designed and built by the Pelton Waterwheel Company; and all the electrical apparatus, including the generators, switchboards, transformers, head-gate motors, limit switches, float switches, accessories, and motors for driving the oil pumps, was designed and built by the General Electric Company. The details of design and manufacture of all this apparatus were subject to the approval of the Isthmian Canal Commission's engineers.

The shipping weight of the material furnished by the Pelton Water Wheel Company, including the auxiliary electrical apparatus purchased by them from the General Electric Company, was approximately one thousand tons.

The "Aquitania" and the "Vaterland."

THE "Vaterland" is the largest ship in the world, both as regards tonnage and dimension. Her gross tonnage is 58,000, her length 950 feet, and her breadth 100 feet. The "Aquitania" has a gross tonnage of 47,000, a length of 901 feet, and a breadth of 97 feet. Steam is derived in the "Vaterland" from forty-six single-ended water-tube boilers, and is generated at a pressure of 235 pounds per square inch. The total heating surface is 203,000 square feet, and the total grate area 3,760 square feet. In the "Aquitania" there are twenty-one large double-ended tank boilers, each with eight furnaces. Steam is generated at a pressure of 195 pounds per square inch. The total heating surface is 138,596 square feet, and the total grate area 3,542 square feet. Her propelling machinery consists of triple-expanson turbines of the Parsons action type driving four screws. Her total ahead horse-power averages 56,000, giving a normal speed of about 23 knots. The engines of the "Vaterland" are triple-expansion turbines of combined impulse and Parsons type driving four screws. The ahead horse-power is about 72,000, giving an average speed of 23½ knots. The full complement of passengers and crew in the "Vaterland" is 6,350, in the "Aquitania," 4,202.

Fluid Motions*

Some Problems Awaiting Solution

By the Right Hon. Lord Rayleigh, O.M., F.R.S.

It is apparent that in dealing with a large and interesting class of fluid motions we cannot go far without including fluid friction, or viscosity, as it is generally called, in order to distinguish it from the very different sort of friction encountered by solids, unless well lubricated. In order to define it, we may consider the simplest case where fluid is included between two parallel walls, at unit distance apart, which move steadily, each at its own plane, with velocities which differ by unity. On the supposition that the fluid also moves in plane strata, the viscosity is measured by the tangential force per unit of area exercised by each stratum upon its neighbors. When we are concerned with internal motions only, we have to do rather with the so-called "kinematic viscosity," found by dividing the quantity above defined by the density of the fluid. On this system the viscosity of water is much *less* than that of air.

Viscosity varies with temperature; and it is well to remember that the viscosity of air increases while that of water decreases as the temperature rises. Also that the viscosity of water may be greatly increased by admixture with alcohol. I used these methods in 1879 during investigations respecting the influence of viscosity upon the behavior of such fluid jets as are sensitive to sound and vibration.

Experimentally the simplest case of motion in which viscosity is paramount is the flow of fluid through capillary tubes. The laws of such motion are simple, and were well investigated by Poiseuille. This is the method employed in practice to determine viscosities. The apparatus before you is arranged to show the diminution of viscosity with rising temperature. In the cold the flow of water through the capillary tube is slow, and it requires 60 seconds to fill a small measuring vessel. When, however, the tube is heated by passing steam through the jacket surrounding it, the flow under the same head is much increased, and the measure is filled in 26 seconds. Another case of great practical importance, where viscosity is the leading consideration, relates to lubrication. In admirably conducted experiments Tower showed that the solid surfaces moving over one another should be separated by a complete film of oil, and that when this is attended to there is no wear. On this basis a fairly complete theory of lubrication has been developed, mainly by O. Reynolds. But the capillary nature of the fluid also enters to some extent, and it is not yet certain that the whole character of a lubricant can be expressed even in terms of both surface tension and viscosity.

It appears that in the extreme cases, when viscosity can be neglected and again when it is paramount, we are able to give a pretty good account of what passes. It is in the intermediate region, where both inertia and viscosity are of influence, that the difficulty is greatest. But even here we are not wholly without guidance. There is a general law, called the law of dynamical similarity, which is often of great service. In the past this law has been unaccountably neglected, and not only in the present field. It allows us to infer what will happen upon one scale of operations from what has been observed at another. On the present occasion I must limit myself to viscuous fluids, for which the law of similarity was laid down in all its completeness by Stokes so long ago as 1850. It appears that similar motions may take place provided a certain condition be satisfied, viz., that the product of the linear dimension and the velocity, divided by the kinematic viscosity of the fluid, remain unchanged. Geometrical similarity is presupposed. An example will make this clearer. If we are dealing with a single fluid, say air under given conditions, the kinematic viscosity remains, of course, the same. When a solid sphere moves uniformly through air, the character of the motion of the fluid round it may depend upon the size of the sphere and upon the velocity with which it travels. But we may infer that the motions remain *similar*, if only the product of diameter and velocity be given. Thus, if we know the motion for a particular diameter and velocity of the sphere, we can infer what it will be when the velocity is halved and the diameter doubled. The fluid velocities also will everywhere be halved at the *corresponding places*. M. Eiffel found that for any sphere there is a velocity which may be regarded as critical, i. e., a velocity at which the law of resistance changes its character somewhat suddenly. It follows from the rule that these critical velocities should be inversely proportional to the diameters of the spheres, a conclusion in pretty good agreement with M. Eiffel's observations.[1] But the principle is at least equally important in effecting a comparison between different fluids. If we know what happens on a certain scale and at a certain velocity in *water*, we can infer what will happen in *air* on any other scale, provided the velocity is chosen suitably. It is assumed here that the compressibility of the air does not come into account, an assumption

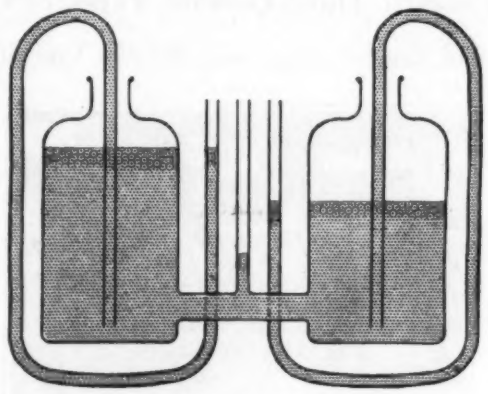


Fig. 1

which is admissible so long as the velocities are small in comparison with that of sound.

But although the principle of similarity is well established on the theoretical side and has met with some confirmation in experiment, there has been much hesitation in applying it, due perhaps to certain discrepancies with observation which stand recorded. And there is another reason. It is rather difficult to understand how viscosity can play so large a part as it seems to do, especially when we introduce numbers, which make it appear that the viscosity of air, or water, is very small in relation to the other data occurring in practice. In order to remove these doubts it is very desirable to experiment with different viscosities, but this is not easy to do on a moderately large scale, as in the

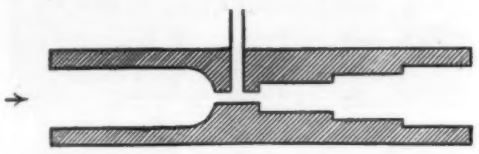


Fig. 2.

wind channels used for aeronautical purposes. I am, therefore, desirous of bringing before you some observations that I have recently made with very simple apparatus.

When liquid flows from one reservoir to another through a channel in which there is a contracted place, we can compare what we may call the *head* or driving pressure, i. e., the difference of the pressures in the two reservoirs, with the *suction*, i. e., the difference between the pressure in the recipient vessel and that lesser pressure to be found at the narrow place. The ratio of head to suction is a purely numerical quantity, and according to the principle of similarity it should for a given channel remain unchanged, provided the velocity be taken proportional to the kinematic viscosity of the fluid. The use of the same material channel throughout has the advantage that no question can arise as to geometrical similarity, which in principle should extend to any roughness upon the surface, while the necessary changes of velocity are easily attained by altering the head, and those of viscosity by altering the temperature.

The apparatus consisted of two aspirator bottles (Fig. 1) containing water and connected below by a passage bored in a cylinder of lead, 7 centimeters long, fitted water-tight with rubber corks. The form of channel actually employed is shown in Fig. 2. On the upstream side it contracts pretty suddenly from full bore (8 millimeters) to the narrowest place, where the diameter is 2.75 millimeters. On the down-stream side the expansion takes place in four or five steps, corresponding to the drills available. It had at first been intended to use a smooth curve, but preliminary trials showed that this was unnecessary, and the expansion by steps has the advantage of bringing before the mind the dragging action of the jets upon the thin layers of fluid between them and the walls. The three pressures concerned are indicated on manometer tubes as shown, and the two differences of level representing head and suction can be taken off with compasses and referred to a millimeter scale. In starting an observation the water is drawn up in the discharge vessel, so far as may be required, with the aid of an air-pump. The rubber cork at the top of the discharge vessel necessary for this purpose is not shown.

As the head falls during the flow of the water, the ratio of head to suction increases. For most of the observations I contented myself with recording the head for which the ratio of head to suction was exactly 2:1, as indicated by proportional compasses. Thus on January 23rd, when the temperature of the water was 9 deg. Cent., the 2:1 ratio occurred on four trials at 120, 130, 123, 126, mean 125 millimeters head. The temperature was then raised with precaution by pouring in warm water with passages backward and forward. The occurrence of the 2:1 ratio was now much retarded, the mean head being only 35 millimeters, corresponding to a mean temperature of 37 deg. Cent. The ratio of head to suction is thus dependent upon the head or velocity, but when the velocity is altered the original ratio may be recovered if at the same time we make a suitable alteration of viscosity.

And the required alteration of viscosity is about what might have been expected. From Landolt's tables I find that for 9 deg. Cent. the viscosity of water is 0.01368, while for 37 deg. Cent. it is 0.00704. The ratio of viscosities is, accordingly, 1.943. The ratio of heads is 125:35. The ratio of *velocities* is the square-root of this, or 1.890, in sufficiently good agreement with the ratio of viscosities.

In some other trials the ratio of velocities *exceeded* a little the ratio of viscosities. It is not pretended that the method would be an accurate one for the comparison of viscosities. The change in the ratio of head to suction is rather slow, and the measurement is usually somewhat prejudiced by unsteadiness in the suction manometer. Possibly better results would be obtained in more elaborate observations by several persons, the head and suction being recorded separately and referred to a time scale, so as to facilitate interpolation. But as they stand, the results suffice for my purpose, showing directly and conclusively the influence of viscosity as compensating a change in the velocity.

In conclusion, I must touch briefly upon a part of the subject where theory is still at fault, and I will limit myself to the simplest case of all—the uniform shearing motion of a viscous fluid between two parallel walls, one of which is at rest, while the other moves tangentially with uniform velocity. It is easy to prove that a uniform shearing motion of the fluid satisfies the dynamical equations, but the question remains: Is this motion stable? Does a small departure from the simple motion tend of itself to die out? In the case where the viscosity is relatively great, observation suggests an affirmative answer; and O. Reynolds, whose illness and comparatively early death were so great a loss to science, was able to deduce the same conclusion from theory. Reynolds's method has been improved, more especially by Prof. Orr of Dublin. The simple motion is thoroughly stable if the viscosity exceed a certain specified value relative to the velocity of the moving plane and the distance between the planes; while if the viscosity is less than this, it is possible to propose a kind of departure from the original motion, which will increase *for a time*. It is on this side of the question that there is a deficiency. When the viscosity is very small, observation appears to show that the simple motion is unstable, and we ought to be able to derive this result from theory. But even if we omit viscosity altogether, it does not appear possible to prove instability *a priori*, at least so long as we regard the walls as mathematically plane. We must confess that at the present we are unable to give a satisfactory account of skin-friction, in order to overcome which millions of horse-power are expended in our ships. Even in the older subjects there are plenty of problems left!

* From a discourse delivered at the Royal Institution on March 20th and reported in *Nature*.

[1] *Comptes rendus*, December 30th, 1912; January 13th, 1913.

Revolving-type motor installation, showing blunt-end at front of fuselage, which is not in keeping with the demands of true stream-line design, and which makes inefficient the center portion of the propeller.

100 h. p., 6-cylinder Mercedes engine in Etrich monoplane. Fuselage with its greatest cross-section about one fifth from the front end, conforming very nearly with demands of stream-line design, and giving greater efficiency to center of propeller.

The Internal Combustion Motor in the Field of Aviation*

Aviation Has Evolved Three General Types of Gasoline Motor

By Howard Huntington, Secretary, Aero Club of America; Chairman Dirigible Committee, Acting Chairman Technical Committee

THIS paper is divided into four parts. The second, third, and fourth, may be characterized by the words: Past, Present and Future.

The first I shall entitle:

I—Prelude and Early History

SCOPE OF PAPER: BREADTH.

Any paper dealing with aviation must be broad in its scope, and the aero motor will have to cover a large field indeed, for the field of aviation is as long as the East is from the West, and as broad as it is long. It has height and depth, also; not merely in the actual, but figuratively speaking as well; for it opens to us a new and deep philosophy of the proper proportions of things, the enhanced intercommunication and closer relations between peoples, the lessened importance of country and national spirit in the face of the world point of view; the spirit of world-wide peace, and a new meaning to the Brotherhood of Man under the Fatherhood of God.

SCOPE: LIMITATIONS.

And so in presenting a paper of this nature, although confined to the motor in aviation, I must deal largely in generalities, in order to limit myself to forty minutes. You must not expect me to tell you, for instance, what proportion of carbon and nickel has been found best in steel cylinder construction, or what shape of cam is advisable for high-speed valve operation; but I may very likely tell you that there is *no* critical proportion or shape at all, in these instances, inasmuch as there should be *no* steel cylinder and *no* cams or poppet valves, in the make-up of a dependable aviation engine.

MOTOR POWER NECESSARY FOR FLIGHT.

Soaring flight and manual flight are possible eventualities in the path of progress, and prizes for the actual accomplishment of such flight have already been offered in France. But aviation, as an art, would not exist today, were it not for the development of the last twenty years, in light-weight engines.

AVIATION'S DEBT TO THE AUTOMOBILE.

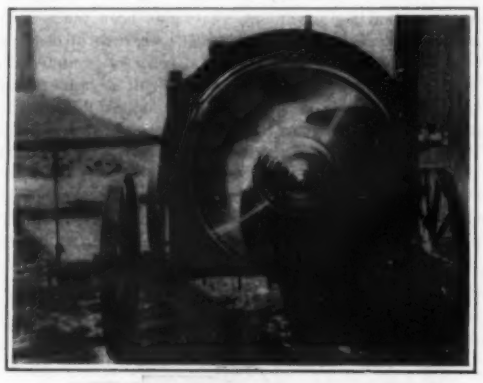
Aviation is deeply indebted to the automobile; and it is to the motorcar, rather than to the internal combustion engine, that aviation owes its present success. Flight was not dependent on the gasoline motor, for the Maxim steam engine was light enough to fulfill the necessary requirements for human flight. This engine weighed 1,800 pounds and delivered 363 horse-power—less than 5 pounds per horse-power. It was installed in a life-size flying machine in 1894—Sir Hiram Maxim's multiplane. And it was no fault of this beautifully constructed power plant that this machine failed to fly. (As most of us know, this machine had more head resistance than lifting surface, and was otherwise poorly designed.) The automobile, also requiring light power, bore the burden of the early steps in light-weight development, both in expansion and explosion motors. And the automobile relieved aviation of a great undertaking, when it determined by long experiment and at great cost, which of these two types of prime movers should be universally adopted. The Stanley Steamer is the only American steam car sold to-day. Light weight, great reliability, and long endurance, coupled with high power and economy in the consumption of fuel, are the demands for power in the motorcar. And these are the chief requisites for power in the aeroplanes. Yet lighter weight, yet greater dependability, yet longer endurance, together with higher power, and greater fuel economy—these are of the highest import in the designing of power plants for service in all air-going craft.

THE FIRST MOTOR TO PROPEL MAN THROUGH THE AIR.

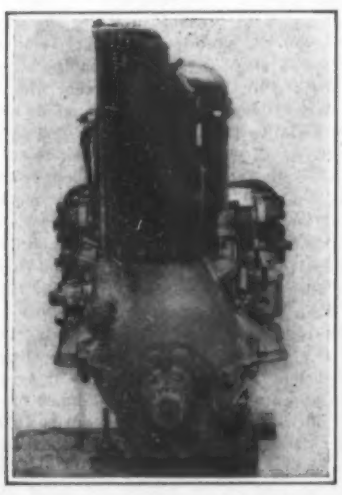
Now when the Brothers Wright, in 1901 and 1902, were ready to equip their glider with power, they turned to the automobile industry for an engine. But after investigation at several factories, being of cautious frame of mind, and rightfully exacting, these two Americans, who knew they had invented the controllable aeroplane, decided that they could improve upon the motors offered them; and accordingly they set to work to build their own engines as well as their planes. They discarded the carbureter, as the weakest element in the gasoline engine, and instituted a system of fuel injection. But otherwise it should be noted, they followed the best automobile practice of that time, and by a process of cutting down the weight in every part rather than by a process of elimination of the parts themselves, they produced a standard four-cylinder upright water-cooled automobile

* Paper read before the New Haven meeting, American Society of Mechanical Engineers, May 1st, 1914.

Upright automobile-type motor installation, conforming very well with the demands of true stream-line design.

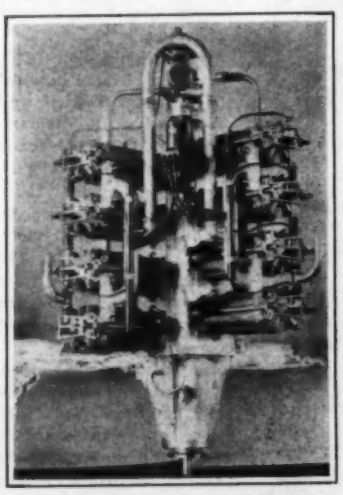


Gnôme air-cooled motor on the testing stand. Beautiful workmanship and balance evidenced by the concentric lines made by the cooling flanges of the cylinders revolving at 1,300 r. p. m.

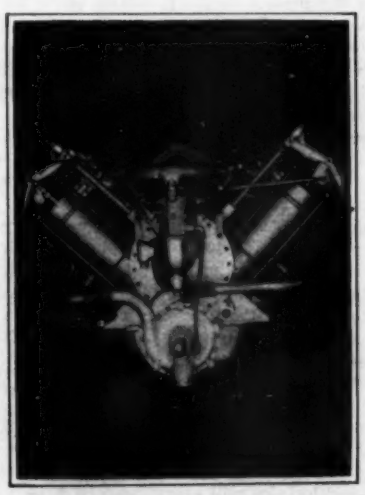


100 horse-power, six-cylinder Benz, showing narrow aspect to the line flight, which makes for comparatively slight head resistance.

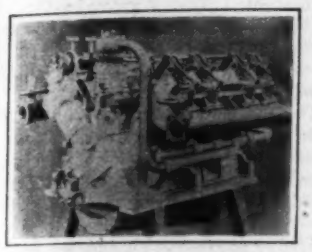
New gyro "duplex" slide intake valve, 80 horse-power motor. The American contender for honors in the revolving air-cooled type.



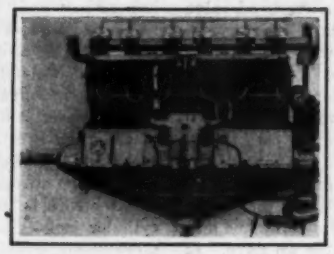
The 100 horse-power Curtiss motor, two of which are installed on the Wanamaker-Curtiss transatlantic flying boat. Top view.



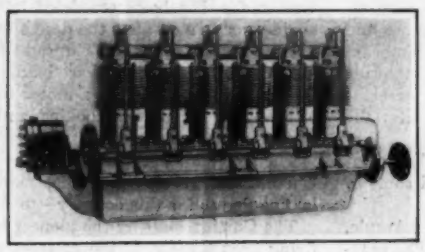
Curtiss 90-100 horse-power motor. End view, showing water-pump placed on main shaft, thus doing away with extra gears, extra shaft, and extra bearings.



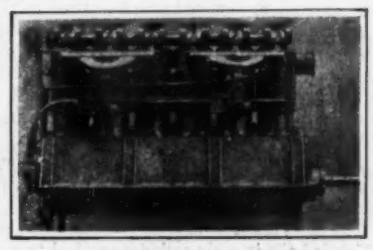
120 h. p., 8-cylinder water-cooled Wolseley aero motor.



100 h. h. p. Mercedes aero engine. The leading German motor.



The Kemp air-cooled motor, showing auxiliary exhausts.



The 120 horse-power British Green engine.

motor, weighing but 7 pounds to the horse-power, which was one half the weight of the best motors of the explosion type to be found at the time. The Brothers Wright in their later motors have followed this upright system, but have come still closer to automobile practice, in adopting the carburetor, which has been brought by the automobile industry to a comparatively high state of perfection.

II—Technical Development in the Past.

THE FRENCH DEVELOPMENT IN REVOLVING ENGINES.

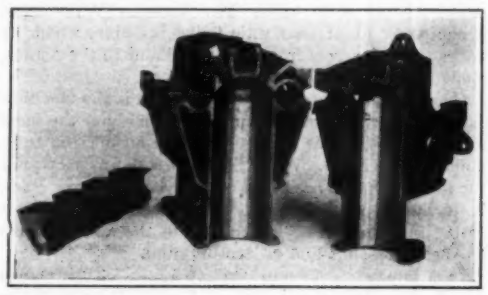
Although America produced the first flying machine, and an American motor was the first to fly, we must admit to our shame that we have left the invention, which we gave to the world, for others to develop. In the years between 1908 and 1912, France produced more in the field of aviation than any other country—or, one might as well say, than all other countries combined. This was chiefly due to their great skill in motor building. I say building rather than designing, because the greatest French motor—the Gnôme—was almost a replica of a poorly built but well-designed American motor, the Adams-Farwell; and of the beautifully designed and well-built Manly motor, which would have been the first to fly in 1903, but for a failure in the launching of the Langley aerodrome nine days before the Wright Brothers' first flight.

This Gnôme engine constructed by skilled French mechanics proved such a marvel of workmanship, that it soon carried most of the aviation records from America to France.

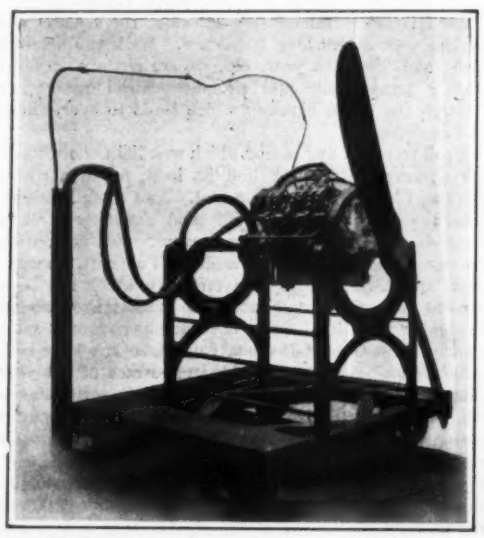
The first great achievement by the French, however, in the actual art of flying, was the crossing of the Channel in July, 1909, by Louis Blériot. This flight of about half an hour is the more wonderful in the light of present knowledge, in the fact that it was accomplished by an air-cooled engine which, never before or since, has been used for more than a few minutes at a time. The Anzani three-cylinder, single-throw-crank, air-cooled engine deserves honorable mention in the annals of aero-motors, for this flight alone, as it has never been of great service to the cause of aviation. We may dismiss it as an admirable attempt—for it was well built—to cool an engine with air without resorting to force-draught or revolving cylinders.

The real contribution which the French have made to aviation, even greater than their development of the monoplane, is the revolving motor. The Gnôme is a beautiful piece of workmanship. In operation, it is so perfectly balanced that one can count the cooling flanges on the cylinders, though they are revolving about the stationary crankshaft at 1,200 or 1,300 revolutions per minute. In the different models seven, and even nine, cylinders, are placed radially about a single crankcase, which weighs approximately the same as would a crankcase for two similar cylinders, set along on an ordinary crankshaft. This elimination of a long crankcase favors light-weight construction; and, of course, the shortness of the crankshaft is another factor in this respect. The fact that the force of combustion in each cylinder is transmitted to the same crank bearings and even to the same crank pin, does not imply in this case that these parts must be heavier to stand an extra strain; for the strain is, in truth, appreciably less, as the firing order in the cylinders of these engines, having an odd number of cylinders, is 1–3–5–7–9–2–4–6–8–, and 1 again, making an even torque, with nine impulses to every two revolutions of the cylinders. And in an ordinary crankshaft with four or six throws—and the encumbent bearings also to add weight—the explosive force in some of the cylinders must be transmitted against the load, not only useful load, but load partially expended in the friction of the other bearings, and in compressing the charge in the other cylinders at the other end of the crankshaft, through many crank arms and bends. And such crankshaft must be heavy, as well as long, to stand the twisting strain. And so here again, the Gnôme or Manly system is inherently light in weight, through design rather than through cutting down the factor of safety in materials. The cylinders of these motors are of nickel steel, bored out from the solid bar. They are machined and ground inside and out. This type of cylinder makes for light weight. The cooling by air really succeeds in this engine, and the cylinders work at approximately as low a temperature as the average water-cooled engine. This cooling system is an elimination and not a cutting down of weight, and it is a real factor in reliability to dispense with the water-works and plumbing of the usual cooling method. There is no radiator to leak, no hose connection to vibrate loose, no cylinder jacket to fill up with deposit or freeze, no pump to fail, no water to boil or evaporate away. And so for the reasons here outlined, the Gnôme is, by its design, a very light-weight motor. Of all the prominent engines which have won laurels in the field of aviation, the revolving motor is the lightest, weighing approximately 3 pounds per horse-power in the smaller sizes, and 2½ pounds per horse-power in the larger units.

But let us look for a moment at the disadvantages inherent in the revolving type. The charge for the cylinders must enter through the shaft, the crankcase, and the piston end of the combustion chamber. This militates against a variation of the amount of gas admitted, owing to mixing difficulties in the crankcase, with the result that at any speed except the critical speed, the Gnôme is very inefficient on power per unit weight of gasoline. Even at the critical speed, it is not very efficient in this respect. On account of the valve action in the piston head, and because of the complexity of small bearings at the crankpin and on the lower end of the master connecting-rod, it has been found advisable to run this motor at a comparatively low compression. This is also a factor against fuel economy. It is true, too, that a slight but appreciable waste takes place in the power required to revolve the seven-, nine-, fourteen-, or twenty-one cylinders, which are continually rushing into new and relatively stationary air. In some machines, where a long fuselage is used, the nose has to be much more blunt than called for by the demands of true streamline formation, in order to house this motor, which must be placed broadside to the line of flight. This detriment of greater head-resistance over the narrow upright motor, is of real importance in some applications. Even the V-type motors display but half as much surface for resistance.



Cylinder castings of the Speedwell rotary-valve motor, sawed in cross section to show the water jacket circulation, rotary-valve housings and the cylinder head formation giving an ideal spherical combustion chamber.



Hall-Scott aviation motor on testing stand.

Now, as I have pointed out before, this motor is a beautiful piece of workmanship. There is one questionable element in it, however, which is not a matter of design but of construction. The cylinders are steel, bored out of the solid billet, and while they are of course light in weight, they are not free from a gradual warp, cutting down their lasting qualities, and they require for proper lubrication abnormal amounts of oil, and the oil required is very expensive pure castor oil. Another point of inefficiency in the *design* is found in the automatic intake valves, which do not open as early by suction as they should for the intake of a full charge.

(The Société des Moteurs Gnôme have just now brought out a new model with some improvements, called the Mono-Soupape, or single-valve Gnôme, but as that has not yet won any great laurels in the art, we must not admit it here to our brief discussion.)

Several firms have followed the lead of the Gnôme into the revolving school, and the Rhône with mechanical intake valves has won considerable distinction. But the real difficulty with this type is the waste of oil and the inefficient use of gasoline. Practically all the attempts to follow the Gnôme into the revolving field, with the exception of the American Gyro, have been of French origin; and, although Santos Dumont, who was the first to make a jump or fly at all in France, used a V-type Antoinette motor, it may definitely be said that France's contribution in the field of aero-motors has been the revolving radial type.

THE GERMAN DEVELOPMENT IN UPRIGHT AUTOMOBILE-TYPE ENGINES.

The Germans, with their customary independence and thoroughness, have held that aviation demanded in motive power just what the automobile demanded, only to a more perfect degree. They were, however, too conservative to launch out, as did the French, into radical or radial ideas!

The Austro-Daimler, though built just outside of Germany, was used so extensively by the German aviators in 1912 that it must be mentioned in this category. It was the first motor in Europe to hold its own against the Gnôme. With six cylinders set upright along a strongly built crankshaft, it follows motorcar practice very closely. The design not being inherently light in weight, the cutting down of materials was resorted to, but apparently with no evil effects, except in one particular. Some trouble was experienced with the copper water jackets leaking at the joints, owing partly to vibration.

The Benz, a very efficient engine which developed 100–103 horse-power for seven hours on 0.58 pounds of gasoline and oil per horse-power hour, in an official test, is another example of this type. The Benz has carried to the highest degree the doctrine of dispensing with piping and connections, by arranging for many leads and ducts in the castings.

The most renowned of this German school of water-cooled automobile-type engines is the Mercedes. Here we have a beautifully designed and beautifully constructed engine, along conventional lines, but skilfully cut down in weight to a degree where durability is not impaired. The cylinders, unlike the Gnôme, follow established practice, being cast in a hard gray iron, which lubricates readily and wears well. The length of the connecting-rods is to the length of the stroke in the ratio of 4 to 1, which is a safe and satisfactory relation. Some engines, striving for light weight, cut this down to even 3 to 1, but what they save in shorter cylinder walls and in the length of the rods themselves, is counteracted by the greater friction of the piston due to the greater angle of thrust, and by the fact that the rod and pins must be proportionately heavier.

This Mercedes engine, with radiator and water complete, weighs approximately 4¼ pounds to the horse-power; which means, in a 100 horse-power unit, about 125 pounds more weight than in a Gnôme giving the same power. The new six-cylinder Mercedes is very economical of fuel, using barely ½ pound per horse-power hour. This motor has, in the past year, taken most of the endurance and long distance records away from France. It stands to-day as the most efficient and most respected motor in Europe.

THE BRITISH DEVELOPMENT IN CURTISS V-TYPE MOTORS.

And now following Blériot across the channel, we find a few British patriots flying behind a Green or a Sunbeam "All British made" engine. But the majority put pride in their pockets and pay up the reluctant six or eight hundred pounds required by the Gnôme people for the old stand-by.

The British engines, however, while they have not come into great popularity, are well built, and some of them are admirably designed.

The most interesting *design* among them is the Argyle, which is built in a six-cylinder vertical type. The noteworthy feature in this engine lies in the fact that there are no poppet valves or cams. The intake and exhaust of the gases takes place through ports opened and closed by a sliding sleeve, something after the fashion of the Knight system. There is only a single sleeve, however, which not only operates in an up-and-down direction, but with a twisting motion as well. This engine, weighing about 5 pounds to the horse-power, and developing 130 horse-power at 1,200 revolutions per minute, used, in a test, only 0.48 pound of fuel per horse-power hour.

But the most beautifully *constructed* British engines are the Sunbeam and the Wolseley. These follow the lead of Curtiss in the V-type arrangement of the cylinders, and we might take these as representatives of the highest development in British engines. Their partiality toward this type is evidenced in the fact that a British firm of high repute—the Austin Works—has arranged for the manufacture of Curtiss motors at their works in England.

The Sunbeam engine—of automobile racing fame—is built in sizes up to twelve cylinders and 225 horse-power. As the number of cylinders and the power increase, engines seem to gain not only lightness in weight per horse-power, but economy in fuel consumption. This monster twelve-cylinder engine weighs complete only 650 pounds, and uses slightly less than 0.48 pound of fuel per horse-power hour.

THE HETEROGENEOUS ASSORTMENT OF AMERICAN MOTORS.

And now with what motor shall we flit across the ocean to America? We hope that the first flight over the waters of the North Atlantic will be under the American flag, and we hope that our machine will be powered with an American motor. The Wright motors we have already mentioned. It is interesting to note that in the early days of the art, in this country, there were many who held that because the two-cycle engine exploded twice as many charges per revolution of the crankshaft, it should have twice the power, or perhaps, allowing for incomplete scavenging, 50 per cent greater power than the four-cycle type. There were in this two-cycle school, the Elbridge of Rochester, the Emerson of Virginia, the Fox from Kentucky, and the Roberts from Ohio. The writer still has hope that the two-cycle principle, which is ideally simple, may some day be worked out to deliver power at least equal to the four-cycle system.

The Manly motor, built in 1901, run for hours in dynamometer tests during 1902, and installed in the ill-fated Langley "Aerodrome" in 1903, is really the first practical aero-motor ever produced. After more than ten years since the unfortunate launching of the Langley aeroplane on the Potomac River, this same motor, with its five revolving cylinders of 5-inch bore and 5½-inch stroke, developing 52 horse-power, was brought to Hammondsport, and flown this spring over the waters of Keuka Lake, in the same old machine, long known in Congress and the press as "Langley's Folly." Mr. Glenn H. Curtiss piloted the machine in this historic flight, and in so doing vindicated the broken-hearted Langley, by proving that he had found the secret of flight, and had built the first motor-driven aeroplane capable of carrying man through the air.

The Gyro is the only successful rotating motor we have produced since the trials of the Manly engine in 1903. In design it would appear to be ahead of the standard Gnôme, having a very ingenious valve-lifting device, and various other refinements. But for some reason it has not attained great popularity, although it has had an American endurance record to its credit. The builders of this motor, the Gyro Motor Company, of Washington, D. C., will bring out shortly a new 80 horse-power single-valve model, and there is every prospect that this motor will be brought to a successful issue. This new Gyro weighs 225 pounds, complete with pumps, magneto and tachometer, and is extremely simple in design, because the old mechanical intake poppet valve in the piston head is replaced by a sliding valve outside the cylinder, which not only simplifies the mechanical part, but takes a great deal of weight from the piston. This is an item of moment, when the actual weight is multiplied by the centrifugal pressure constant.

The Sturtevant, built in Boston, is an example of the automobile-type construction. But unlike the German exponents of this type, the Sturtevant has run into high speed, their newer models attaining their rated power at 1,900 to 2,000 revolutions per minute.

The Maximotor, originally an old L-head automobile-type engine, has been remodeled into an overhead-valve engine, very much after the design of the German Benz. The Kemp is a six-cylinder upright motor with air cooling. As the rear cylinders are blanketed from the air by those in front, this is not a motor for long flight, but it is nicely designed, trim-looking and weighing about 6 pounds per horse-power.

The Hall-Scott, built in San Francisco, is a copy of the Curtiss, and well built. It has many fine flights—that is, fine flights for this country—to its credit.

The Curtiss, built by the pioneer hydro-aeroplane and flying boat builder, is the greatest motor we have. It is the only American motor which is to-day being sold to the armies and navies of Europe.

V-type, and of eight cylinders, with a bore and stroke of 4 inches by 5 inches, it develops 90–100 horse-power at 1,350 to 1,500 revolutions per minute. These engines, built up in lots of a dozen or so at a time, are turned out at the Hammondsport factory at the rate of about two a week. The price of $2,800 compares favorably with any of the French or German engines, except the Benz 100 horse-power, which sells for about $2,600.

The Curtiss engine under load at 1,350 revolutions per minute consumes only 0.52 pound per horse-power hour of fuel. And besides efficiency in fuel consumption, it can claim a weight of 4¼ pounds per horse-power. And, too, it is probably one of the most dependable motors in the world. In the hands of a dozen amateur sportsmen last summer and this past winter, these Curtiss power plants have carried their pilots and passengers an aggregate of 150,000 passenger-miles, without a single casualty. I wonder how this compares with the record of American railroads—a delicate subject, perhaps, to be mentioned down here in New England! It is two of these 100 horse-power motors with which Mr. Rodman Wanamaker is equipping his transatlantic flying machine, which he hopes to send across from Newfoundland to the Azores, Spain, and England this summer.

One of the advantages of the V-design is the fact that eight cylinders can be accommodated on about the same length of shafting as four cylinders in an upright automobile-type engine. While the shaft is not as short, nor the bearings as few, as in the case of the one-throw crank in the radial engines, this system avoids the disadvantages of the rotating air-cooled engines in the matter of extravagant gasoline and oil consumption.

It is interesting to note that it was a V-type engine with which Mr. Curtiss won the Gordon-Bennett International Cup in 1909, in France; and that he is still holding to the same general design.

So much for the past development up to the present time.

III—Influences and Present Tendencies.

THE EFFECT OF LONG DISTANCE FLYING.

As aviation advances step by step, the records are broken with astonishing frequency. With the art but little more than ten years old, we are already contemplating transoceanic and circumterrestrial navigation through the broad highway which leads to everywhere and anywhere.

Until recently, any motor which was light enough per horse-power to lift itself and its load, found a ready market, for to fly was wonderful. And many, indeed, were the accidents due to slipshod assembly of such vital elements as the ignition system. But now, with greater skill acquired in the handling of aircraft, we want great speed. This induces a tendency which has been present since the first flight of the Wright Brothers on December 17th, 1903, when 12 horse-power proved sufficient. Each Gordon-Bennett Cup Race has been won with higher-powered engines than the race of the year preceding. Last summer, in France, this aerial classic was won with a twenty-one cylinder 200 horse-power Gnôme, driving the winner around the five kilometer course at the rate of 125 miles per hour, for one hour.

While the desire for greater speed is exerting an influence for greater and greater power, the most potent reason for larger power at the present time is found in the demand for greater lift and larger machines. In Europe, they are no longer satisfied with two-place and four-place craft; England is building "busses" for six and ten passengers, and Germany and France send up similar numbers in "Aerial Transports," and Russia through the admirable audacity of young Sikorsky, has taken an even greater lead over *us*, who taught Europe how to fly. This gigantic Sikorsky biplane recently maneuvered over the city of St. Petersburg with seventeen passengers on board, carried in wicker chairs in a roomy cabin with windows, shades, and curtains, if you please! This machine is propelled with 400 horse-power. And now this same young pioneer is building a biplane to accommodate thirty people and travel at a speed of 100 miles per hour with 1,600 horse-power.

As with the railroad locomotive and the steamship, so with the aeroplane. The cry has ever been: greater radius of action, greater speed, and speed variation, and greater carrying capacity; in other words, more power.

THE INCREASE IN DEPENDABILITY.

Along with this demand comes another cry, fully as imperative and insistent. The Wanamaker-Curtiss transatlantic flyer must send out the S. O. S. call for help back to civilization, if the two 100 horse-power Curtiss engines fail to run the course. Every conceivable mishap is anticipated in the design and construction of these engines. And indeed one of the greatest tendencies of the year 1914 is the doubling up of delicate parts.

We find intake and exhaust valves coming out in duplicate. Magnetos are also double on several new designs. Greater care is used in manufacturing methods. The cylinder jackets are welded on to the cylinder ribs by more expensive and better processes. The bearings which are such a vital element in the long life of any piece of machinery are much heavier and of better material.

WATER VS. AIR COOLING.

In the matter of cooling, there has been much division of opinion. The leading aeronautic countries of Germany and France are, again, in this matter, on the opposite sides of the fence. The French motors have been mostly air-cooled. The Esnault-Pelterie and the Anzani have never accomplished very much, because they attempted to cool radial but stationary cylinders, with merely the flow of air past the machine. The Renault, a V-type engine which we have not had time to discuss, succeeds in cooling itself by means of a fan. A rotary fan at one end of the crankcase blows a forced draft through a system of aluminium channels and deflectors to each cylinder. But I say it succeeds in cooling. It also succeeds in adding complication, cumbersomeness and weight, to a degree which makes water cooling more efficient.

The Gnôme and Rhône rotating motors cool well and are inherently light in weight; but at the expense of efficiency in other ways above described.

The Germans, again following the lead of the automobile engineer, have held fast to that which is good, and, with water-cooled engines, have succeeded in taking records away from France, until to-day Germany stands first in aerial development.

It would appear that the aeroplane would find more air about it to cool its engine than would the motorcar. But there is really very little difference; why, in fact, theoretically, there is more air down on the ground than there is above! The aero engine is traveling faster into the new cool air than is the automobile engine, but it is also working at a higher number of revolutions per minute, and under greater and more constant load. And so, I would say that in this important phase of the design of aero-motors, the question is very similar to the same problem in automobile engineering, and will result in the same decision. There are but two automobile companies of any size left in this country with an output of air-cooled cars.

THE IGNITION.

In the field of ignition there seems no reason to be dissatisfied with the present magneto. The only noticeable tendency in this matter seems to be along the lines of doubling up, with two complete and separate systems. Some are adopting the simultaneous spark in two plugs wired in series, to get a more rapid burning of the charge. This had been found in laboratory tests to increase the power of a given cylinder capacity by 3 or 4 per cent.

CARBURETION.

In carburetion, we have taken what the automobile has given us and have found it sufficient unto the day. But with the price and quality of gasoline gradually changing in the inverse ratio, we find a tendency to experiment with carbureters adapted to the use of kerosene and other fuels. Mr. Curtiss has been experimenting with some success in this direction.

IV—The Goal, and a Look to the Future.

STANDARDIZATION INEVITABLE.

At present, in the various problems confronting us, we are in that position where it often appears that the line of least resistance, and therefore of most rapid progress, lies on the other side of the way. But as we stretch out our imaginations and look down the long highway of progress, we find that the paths on each side of the way converge, and there appears to be less difference between them the farther down we look. This may be due to perspective, but it is nevertheless symbolic of the process of standardization. All branches of industry, as the output increases, standardize that output. The aeroplane motor industry will prove no exception to the rule. It will do this in manufacturing methods, and in type and accessories, but not to the same degree of detail as in the case of the automobile motor; for the latter is confined in size and operation to the demands of roadways, limiting size and speed.

FUEL ECONOMY VS. LIGHT-WEIGHT DESIGN AND CONSTRUCTION.

With the great strides of the last decade, and the surety of yet greater strides in the decade ahead of us, we must realize one paramount certainty: the use of aircraft for rapid transit from north to south, and from shore to shore. Except for short-distance flying in run-about machines, this spells the doom of French rotating motor. Even in the new Mono-Soupape Gnôme, which has as yet to prove itself in duration flying, efficiency is

claimed chiefly in the matter of lubrication, and it is generally believed that the revolving type can never attain to the gasoline economy of the stationary engine. This means that the advantage of light-weight in the engine holds only for short-distance flying. The weight of the fuel, which must be carried for long flights with the Gnôme or Rhône motors, incurs a weight greater than that of the fuel for the stationary cylinders, and the added weight of the stationary motor itself.

And so we find that for any flight of over four hours' duration, the heavier type of *engine* makes the lightest *power plant*. To cross the ocean with a 200 horse-power Gnôme power-plant, the machine *in toto* would weigh about 1,600 pounds more than with a 200 horse-power Curtiss V-type power plant.

THE AIM IN AERO-MOTOR DESIGNING.

In the next ten years the development must follow along the lines of fuel economy and reliability. The requisites for power in the aeroplane will be the same as outlined under my sub-heading, "Aviation's Debt to the Automobile." But "light weight" will be applied to the whole power plant, including tanks and fuel, and not so much to the engine itself. In other words, the order will be, greater dependability, longer endurance, greater fuel economy, coupled with high power and light weight.

THE THREE GENERAL TYPES COMPARED.

We have discussed three general types. One very naturally inquires which of these is to be the ultimate equipment for the aeroplane. The writer believes that each has a distinct field of its own, and his personal opinions as to the relative merits, and the respective fields of service, of the three general types, may be stated in brief as follows:

In the first place, the upright automobile-type engine, which has attained such signal success in Germany, will always find a market, in sizes up to 150 or 200 horse-power. Its simplicity makes for dependability; and in applications where no fuselage breaks its hole of passage in the air, it will be a favorite on account of its narrow aspect and small head resistance.

The revolving air-cooled type, so successful in France, will find a ready market in aeroplanes of the runabout class, where light weight of *engine* is of first importance, which is usually the case where short radius of action is all-sufficient.

The V-type engine will have the field in the larger machines, where greater radius of action is required, because the revolving-type motor necessitates the carrying of a comparatively greater weight of fuel per ton mile, and the upright automobile-type engine will not be built in large enough units. If the upright motor is to be built in sizes upward of 150 or 200 horse-power, the bore and stroke must needs be larger than has been found practicable, unless an increase in the number of cylinders is resorted to, above the number customary in this type. But six cylinders have been found to be the greatest feasible number which may be placed in a single row along one crankshaft. And as fuel economy is enhanced—above the 150 horse-power size—by an increase in the number of cylinders, rather than by an increase in the bore and stroke, and as the V-type disposition of cylinders admits of twice the usual number of cylinders on approximately the same length and weight of shafting, and with no evil results in the wear and tear of bearings, the V-type motor may be looked to for service in all large machines, and in all other machines designed for long distance flying. A potent reason for my belief in this type for the larger machines is the fact that the stationary type is more economical of fuel than the revolving type. And so, in large machines designed for long cross-country work, the V-type will be actually lighter per horse-power, fuel taken into account, than the revolving power plant. For any flight of over four hours' duration, the heavier V-type water-cooled *engine* will make the lightest *power plant*.

And so we see that these three types, in their respective fields, will undoubtedly persist, each with an ever increasing measure of success.

Of course a great ideal, always before us, is the wireless transmission of electrical power to an electric power plant. The electric motor is so simple that it is easily made dependable. But the electric motor, with its armature and field, is heavy inherently in itself; and this is all too vague a matter to discuss while we are yet awake!

In the gasoline field we have another ideal, which, though not quite so much of a dream, is still only on paper. This is the rotary motor. Distinction must always be made, of course, between the *so-called* rotary motors of the Gnôme type, which I have called rotating, or revolving, motors, and the true rotary engine, in distinction from the reciprocating types. I received an invitation only a day or two ago to look over the designs of a gasoline turbine, of the wizard inventor Nichola Tesla. He claims that he can build a motor of this type to weigh 300 pounds and develop 600 horse-power—one half pound to the horse-power! Dependability is vouched for on the ground that there is only one moving member and three bearings to lubricate. *But*, in the light of present knowledge, the most promising field for development appears to lie in the reciprocating water-cooled four-cycle V-type motor.

NEW FUELS NOT NECESSARY IN THE NEXT TEN YEARS.

New and cheaper fuels will be experimented with, but for the next decade gasoline will be plentiful enough to make it really unnecessary to find something better.

POPPET VALVES WILL GIVE WAY TO SLIDE OR ROTARY VALVES.

The most interesting change that is likely to take place in the design of the reciprocating motor, lies in the probable elimination of the poppet valve. These valves require the inefficient cams to operate them, and about seven out of every hundred horse-power must be expended in opening them against heavy tension springs. The heat at the exhaust valves warps and pits the best tungsten steel valve, and there appears a leakage of compression between it and the valve seat. Wear is a large item in the poppet valve design, and the cams with the pounding push rods are in frequent need of adjustment, and always make a large amount of noise. These valve troubles are of much greater moment in the aeroplane motor than in the automobile, for the former is working at a higher number of revolutions per minute and under a greater and more constant load.

And so, as in the case of the automobile, the demands of long wearing qualities, and of silent operation, will bring about the gradual elimination of the poppet valve. In this development, however, the aero-motor will not follow the lead of the automobile, but the two will go hand in hand, for the automobile is only in the first steps of this process itself. It would really appear that the aero-motor had now practically caught up with the automobile development in internal combustion engines.

The Knight sliding sleeve motor is slowly but steadily gaining a better foothold in the automobile industry, and it may get a slight hold in aviation. But it is the view of the writer that before it triumphs over the poppet-valve engine, another system will overtake both of them. There is a great promise in the rotary-valve engine, if the intake and the exhaust are separate valves. The Mead four-cycle engine, if properly built, will effect a real advance. The writer is at the present time trying to get the owners of the patent to build this engine as it should be built for aviation purposes. It has just now been adopted by one automobile company of high repute as the power plant for all their pleasure cars. This motor will be simple and of few parts. It will therefore be dependable and durable. It will be a trifle lighter in weight inherently than the poppet-valve engine. It will be—already is, in the automobile—a little more economical of both gasoline and oil than either the poppet-valve or the sliding-sleeve motor.

This motor, built in 200 horse-power and 400 horse-power units—eight cylinder and twelve cylinder V-type, respectively—with water-cooling and dual and double ignition, and with large pipes and easy curves in the manifold system, will make a most successful combination.

SAFETY AND MULTIPLICITY OF POWER UNITS.

In closing, I wish to leave one final message with you. It is my earnest belief that aviation will never be as safe a means of cross-country and over-sea transportation as it should be until we discard the idea of hanging our lives up there, in the balance as it were, with one mechanical device as our sole dependence from premature descent, or rather, from premature alighting. No motor, no matter how simple in design, or how perfect in construction, can be 100 per cent reliable. With two motors in the aeroplane, either one of them capable of carrying the machine with the other as dead weight, the safety is much more than doubled. The chance is a very small one that both of these motors will break down at the same moment, or that in such a rare event it should be impossible to find a safe landing. When one motor stops, the careful pilot will steer his ship and passengers to the nearest landing in sight, or have his engineer immediately repair the disabled motor. Machines of the air-going variety will in the future carry two, three, or four—a multiplicity of power units. Russia is already working along these lines. The Sikorsky machine, which carried seventeen people, carried four 100 horse-power water-cooled motors, and in flight, two of these engines were stopped without causing a descent. And report now has it that this young constructor is equipping his 30-passenger craft with four power plants of 400 horse-power each.

CONCLUSION.

May I venture a prophecy? The automobile industry was first an industry in Europe, but to-day nearly nine tenths of the motor car industry is in this country, and it is here that the money is invested. Let us make certain in this matter that "History repeats itself." As the automobile and the motor boat, so the aeroplane. Before this new decade is history, the American motor will lead the world; and with its success, the lead in the *industry* of aviation, the lead in research in the *science* of aviation, the lead in achievement in the *art* of aviation, will all stand to the credit of American genius which gave this invention to Europe and the world; and the laurels in the *sport* of aviation will be brought back to the United States of America.

Some Conditions Inducing Excessive Respiration

It has been pointed out by several investigators[1] that voluntary forced breathing in man may give rise to unpleasant and even alarming symptoms. The outcome apparently depends on a number of modifying factors. As a rule, in a short time after the forced breathing the subject either stops breathing altogether if his respiration is allowed to act involuntarily or he breathes in a very shallow and ineffective manner. Numbness and tingling in the hands and feet are reported to occur; and if the forced breathing has been of considerable duration—two or three minutes or longer—many subjects experience an oxygen want when the subsequent apnea sets in. The lips may turn blue; Cheyne-Stokes breathing may be initiated; and Henderson has called attention further to the occurrence of "light-headedness," polyuria, shivering, muscular weakness and other functional disturbances induced by prolonged forced breathing. He maintains that the symptoms evoked are similar to those of shock, and suggests that death from failure of respiration would probably result from vigorous voluntary hyperpnea for fifteen or twenty minutes.

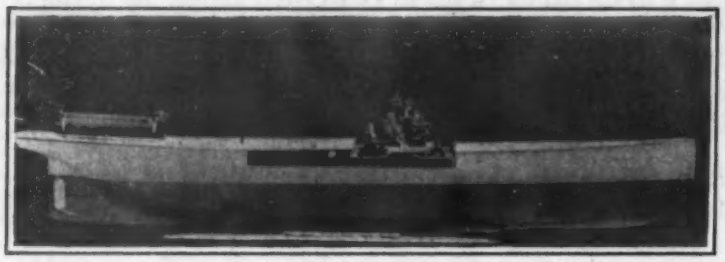
There are various ways in which excessive respiration—hyperpnea—can be induced in man aside from the purely voluntary manner that has just been referred to. Pain is one of the natural stimuli calling forth hyperpnea. Anger, sorrow, fear and ether-excitement may induce a similar result. All of these phenomena may be attended or followed by what is sometimes spoken of as shock. Henderson, as is well known, has argued that the condition of shock which results in man from extreme physical suffering is, to a large extent, caused by the reduction of the carbon dioxid content of the blood and tissues as the result of the violent and prolonged hyperpnea caused by stimulation of afferent nerves. In contrast with this is the view that the ill effects produced by suffering are the expression of fatigue of the nervous system and of the heart, resulting from the intensity of the sensory irritations. This theory of the etiology of shock has been vigorously combated. We have no desire at this time to enter into a discussion of the nature of this much-debated subject. The underlying facts with respect to the physiologic effects of pain and ether, for example, on the respiration in man ought to be demonstrable quite independent of the interpretation which is put on the consequences thereof.

Hitherto much of the experimental work has been conducted on animals under conditions which approached extremes rarely found in man; or in the case of experiments on man the voluntary forced respiration has been somewhat unlike that which might arise in the exigencies of practice. Dr. A. L. Meyer of the University of Pennsylvania has approached the problem of hyperpnea and acapnia in its possible relation to "one of the most important symptom-complexes in medicine" by a direct study of the effect of moderate pain and of the incipient stage of anesthesia in man. In Haldane's laboratory at Oxford, he determined the volume of air breathed, the respiratory exchange, and the alveolar carbon dioxid pressure on human subjects.[2] The device for securing experimentally the effect of moderate pain, the duration of which could be controlled, consisted in placing a clamp on the end of the little finger. This apparatus could be screwed down firmly and then released. The average pain was, according to the investigator, probably such as might be caused by a severe felon.

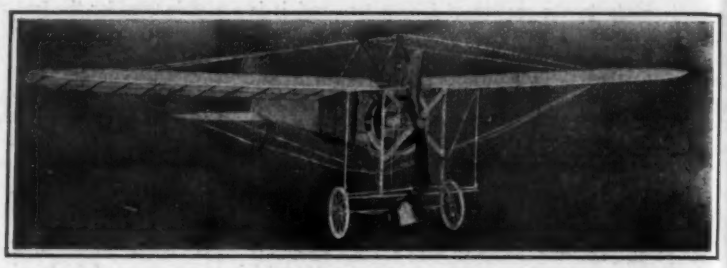
Pain of moderate intensity and short duration (two to three minutes) actually produces hyperpnea that can easily be measured. The alveolar carbon dioxid is diminished and the respiratory quotient increased. Ether in suitable low concentration produces hyperpnea in one minute. How vigorous it may become is illustrated by one case in which an air mixture containing 3.3 per cent of ether produced an increase of 92 per cent in the air respired; and on another occasion a mixture of 2.8 per cent produced an augmentation of 66 per cent. The degree of excessive ventilation of the lungs varies in different persons; and with higher concentrations of ether the breathing is diminished. The alleged possibilities of inducing acapnic conditions in man are accordingly established.—*Journal American Medical Association.*

[1] Haldane and Poulton: *Jour. Physiol.*, 1908, xxxvii, 390. Henderson, Yandell: *Am. Jour. Physiol.*, 1909–10, xxv, 310; Respiratory Experiments on Man, *The Journal of American Medical Association*, April 11th, 1914, p. 1,133.

[2] Meyer, A. L.: Hyperpnoea as a Result of Pain and Ether in Man, *Jour. Physiol.*, 1914, xlviii, 47.



The Schilowsky model gyroscope ship, showing the mechanism for stabilization exposed to view.



The Schilowsky model gyroscope as applied to an aeroplane. The model is suspended on pivots to allow it to oscillate freely.

The Schilowsky Gyroscope*

Its Adaptation for Stabilizing Ships and Aeroplanes

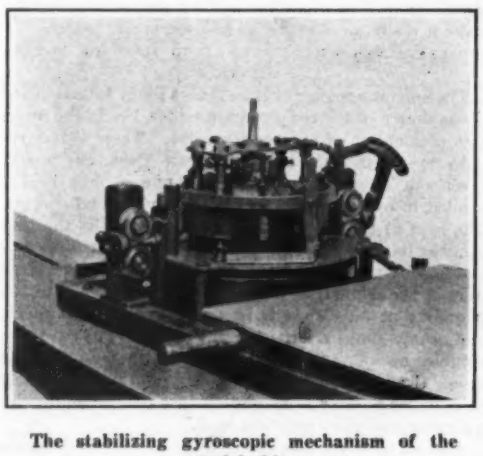
By J. Harris Stone, M.A., F.L.S., F.C.S.

In the May 30th issue of the Scientific American appeared an account of the monorail Schilowsky gyroscope system as applied to trains and motorcars, in other words, to earth-running vehicles. During the last few weeks the Russian inventor has deposited in the South Kensington Science Museum, as presents to the nation, his first completed working models of the gyroscopic invention as applied to the stabilization of ships and of aeroplanes. These two new models with the working monorail train already there, make the South Kensington Science Museum the richest in practical gyroscope appliances in the world; the gyroscope as applied to the stabilization of vehicles on earth, water, and in the air.

The difficulties to be encountered in stabilizing an earth-running vehicle on two wheels are, from a scientific point of view, greater than those to be overcome in an aquatic or aerial conveyance. A ship and also an aerial machine have already a certain amount of inherent stability, owing to the media in which they progress; and their line of support, of equilibrium, being above the center of gravity, theoretically, it were easier to impart a still greater amount of stabilization to such craft than to a motorcar or train. But practically, the difficulties are still great, and it may be long yet before a ship is constructed which is rigid in all directions except that of direct progression, or an aeroplane made which will always rapidly and automatically right itself when upset by blasts of powerful winds or other causes. Now in a ship, if the movement (other, of course, than that of progression) were confined strictly to what is known as pitching—an upward and downward vibration only—sea-sickness and discomfort would, if not nearly obliterated, be rendered much less prevalent. It is when the pitching of a vessel is combined with the horrid rolling motion that the nausea reaches its zenith, and life to so many of us becomes almost unsupportable. The Schilowsky gyroscope, as applied to ships, is an attempt to minimize, reduce, or even to obliterate the rolling. As a ship afloat is a stable but an oscillatory body, the gyroscope is fitted in a stable manner.

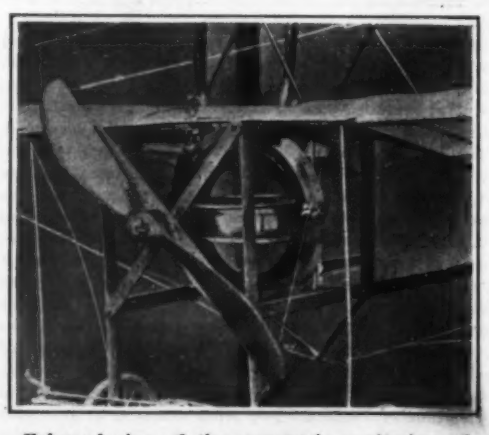
As is shown clearly in our first engraving, the gyroscope is pivoted to the model ship by a system of sliding pivots affixed to it above its center of gravity. If the ship is leaning to either side the gyroscope slides a little along its pivots to the inclined side (port or starboard, as the case may be), and at the same time a suitable arm engages a ratchet device, elastically pivoted to the frame, and this contrivance retards the swinging movement of the gyroscope. M. Schilowsky is the first practical experimenter with gyroscopes to demonstrate that in gyroscopes suspended above the center of gravity, used for stabilizing stable, but oscillatory bodies, it is necessary to bring the troubled gyroscope and the vehicle to their normal positions, and that these results can only be effected by forces just opposite in action to those used for unstable bodies. In place of hurrying up the precision mechanism, a retarding precision device is employed which the inventor calls "antiprecessional." In the model ship at South Kensington it is clearly seen that since the retarding mechanism is put into operation in the vessel, to which an oscillatory motion is given, it restores the horizontal equilibrium of the vessel. Once restored, the gyroscope slides back, and disengagement occurs, leaving the gyroscope ready to repeat the equalizing operation. It is in this device that the peculiar invention of M. Schilowsky is evident.

As in dealing with a ship, we have, as already mentioned, not to stabilize a very unsteady body, like a motor-car or a train: the gyroscope for a ship can be of comparatively trifling weight, and can revolve with comparative slowness. M. Schilowsky is of the opinion, he tells me, that the weight of the ship gyroscope could be decreased to about one half per cent of the total weight of the ship; but I fancy it is extremely difficult, at the present stage of the science, to accept this as an infallible datum. I tried the ship model experimentally, and found that it rocked from side to side—port to starboard—just fourteen times before finding



The stabilizing gyroscopic mechanism of the model ship.

rest; that was when set into rocking motion with the gyroscope not in action. When the gyroscope was revolving, but without the side-ratchet contrivance being in gear, the vessel rocked just one half, or seven times. When the gyroscope was revolving, and the side-ratchet apparatus used for exercising the controlling influence on the instrument (in the model on the starboard side of the ship) brought into play, the rocking movement



Enlarged view of the gyroscopic mechanism of the aeroplane.

was *at once* arrested. So quickly was this effected that it seemed little short of marvelous. It is as if some overruling, sentient power were dominant in the ship, which instantly, when rolling began, said, "No, you shall not roll!" This was apparent when the speed of the gyroscope was decreased to quite a trifling number of revolutions—only about five hundred a minute. With that speed the retarding device stabilized the model ship, though not with the same resistive strength as when it was running at two thousand revolutions.

From this description it will be apparent that there are attached to the gyroscope, as applied to ships, no heavy or large pendula as are used in the instruments for stabilizing land vehicles, for the weight of the gyroscope itself takes the place of those heavy swinging adjuncts attached to the land instrument.

There is a very prevalent opinion that aeroplanes are very unstable—more so than any other vehicle—but this is hardly correct. In reality, an aeroplane is, like a bird, comparatively speaking, stable, but very oscillatory, and loses very easily its stability when a rolling motion is accelerated. It is therefore most important for the safety of those traveling aerially that the rolling motion should be stayed, and an attempt to attain this object is made by the Schilowsky gyroscope. Were the rolling propensity obliterated, the brains and strenuous attention of the pilot in the aeroplane (which are now largely engaged in overcoming the oscillations of his machine) could be directed solely to overcoming the longitudinal—the up-and-down—movements. In the aeroplane model (a beautiful and exact to scale monoplane of Blériot's) at the South Kensington Science Museum the weight of the pilot is represented by a heavy iron weight, and the gyroscope is proportionately not the weight of a single passenger. When the gyroscope was in action in the model I found it difficult to divert it from the horizontal position, even when pressing with some force on the extreme tip of a wing. Its stiffness was remarkable. The action of the gyroscope as applied to the aeroplane is similar to that used for vessels. Each rolling swings over the gyroscope, sliding on pivots, to the inclined side, and during this movement it comes into contact with the retarding spring, and, consequently, the antiprecessional mechanism is brought at once into play, with the result that the aeroplane is restored to its correct plane of flight. In full-sized aeroplanes the same gasoline engine which drives the fan would also cause the gyroscope to revolve, and the alighting of such a fitted aeroplane on earth or water would therefore also be a matter of ease and great delicacy. Altogether, it is not unlikely that in the next few years we shall witness many marvelous, almost revolutionary, improvements in aeroplanes, especially as regards their safety and carrying capacity, some of which, at any rate, will be due to the use of the gyroscope—an instrument which has only just emerged from the status of a nursery toy.

It may be added that the two-wheel (monotrack) motorcar—figured and described in our issue of May 30th—fitted with M. Schilowsky's gyroscope, has been making many runs about London during the last week or two, to the great delight and wonderment of the public.

* Reproduced from *Knowledge*.

The Mechanical Efficiency of Muscle

The muscles of the animal body do not produce their work after the manner of a heat engine; but the chemical energy of the substances used up in muscular work is indirectly converted into mechanical work. An intermediate form of energy which appears in the process is that of turgescence or swelling of the muscle fibers. During the operation of a muscle, lactic acid is liberated, which causes the muscle fiber to swell up. The shortening of the muscle fiber, which thus results, is therefore not referable to a combustion process. The combustion or oxidation occurs only subsequently, when the muscle extends to its normal or quiescent state, and serves to remove the lactic acid, the latter being reconverted into the more complex body from which it originated. The efficiency of this chemical engine is greater than that of our heat engines of commerce.

Napier and the Invention of Logarithms*

The Tercentenary of One of the Greatest Labor-saving Devices Known

By Prof. George A. Gibson, M.A., LL.D.

In 1614 John Napier of Merchiston published his "Description of the Admirable Canon of Logarithms." On the title page of the book he is called their "author and inventor," and the words were the simple statement of a fact, because he was the inventor both of the method of logarithmic calculation and of the word logarithm itself.

At the present day it is perhaps somewhat difficult to form an adequate conception of the greatness of Napier's invention; yet it is beyond all question that the invention of logarithms marks an epoch in the history of science. It is generally admitted that Newton's "Principia" is one of the great works that have shaped the course, not merely of modern science in its practical aspects, but of scientific thought in relation to philosophy and theology. But the debt of Newton to Napier, though indirect, was very real, because Newton was essentially dependent on the results of Kepler's calculations, and these calculations might not have been completed in Kepler's lifetime but for the aid that the logarithms afforded. Kepler felt keenly the grievous burden imposed upon him by the older methods, and was correspondingly gratified by the relief that the new means of calculation provided. Without the logarithms or some similar help, astronomical observations could only have been reduced, if at all, with the very greatest difficulty, and the development of modern science might have followed a very different course.

The significance of Napier's invention becomes all the more remarkable when we consider the condition of Scotland during his lifetime. Throughout the greater part of the sixteenth century there was incessant unrest, and such intellectual interests as made themselves felt were predominantly associated with ecclesiastical and theological discussions. Though the foundation of the University of Edinburgh in 1582 increased the number of universities to four, the higher learning could hardly be said to "flourish," even if we allow for the energetic principalship of Andrew Melville. The instruction given in the universities was necessarily of a very elementary kind, since adequately prepared students were not being sent up from the schools, and there was no scientifically minded public to whom appeal might be made. Before Napier, Scotland made not a single contribution to mathematical science, and the appearance, early in the seventeenth century, in Scotland, of a book that at once took rank as one of the great landmarks of scientific discovery, has been a constant subject of remark by the historians of mathematics.

John Napier, the inventor of logarithms, was born in 1550, at Merchiston Castle, near Edinburgh. Such knowledge as we possess of Napier's private life is due almost entirely to the industry of his descendant Mark Napier, whose "Memoirs of John Napier of Merchiston; His Lineage, Life, and Times" (Edinburgh, 1834), is based on careful research, especially of the private papers of the Napier family, and is the source of all modern accounts.

John Napier was the eighth Napier of Merchiston. According to the "Memoirs," Alexander Napare, the first of Merchiston, acquired that estate before the year 1438 from James I, was provost of Edinburgh in 1437, and was otherwise distinguished in that reign. His eldest son, also Alexander, became in his father's lifetime comptroller to James II, and "ran a splendid career under successive monarchs." The origin of these ancestors of John Napier is very uncertain. In the thirteenth and fourteenth centuries persons of the name of Napier were not uncommon, especially in the Lennox. The Merchiston family cherished a tradition that their name was changed from Lennox to Napier by command of a king of the Scots who wished to do honor to one of their ancestors, Donald, a son of an Earl of Lennox. This Donald, it is said, had turned the tide of battle when flowing strongly against the king, and had fought so valiantly that the king declared before all the troops that he had Na Peer.

It is perhaps of more importance that we do not know the correct spelling of Napier's name since many forms of the word are found, such as Napeir, Nepair, Nepeir, Neper, Napare, Naper, Naipper. Apparently the forms Jhone Neper and Jhone Nepair are the most usual with John Napier; the form Napier is said to be comparatively modern.

When John Napier was born his parents must have been very young, not more than sixteen. Of his boyhood and early education very little is known; the only reference on record occurs in a letter of date December 5th, 1560, when he was about ten years old, to his father from the Bishop of Orkney, Adam Bothwell. The letter contains the following passage:

"I pray you, schir, to send your son Jhone to the schuyllis; oyer to France or Flandaris; for he can leyr na guid at hame, nor get na proffeitt in this maist perullous worlde—that he may be saved in it—that he may do frendis efter honnour and proffeitt as I dout not bot he will: quhem with you, and the remanent of our successioune, and my sister, your pairte, Got mot preserve eternalle."

It is possible that the bishop had already detected indications of the genius that was later to become so manifest, but it seems to me more likely that the interest shown in the son was intended to stimulate the father to exert himself on the bishop's behalf in certain legal proceedings which form the main subject of the letter.

In 1563, John Napier's mother died, but before her death he had matriculated at St. Salvator's College, St. Andrews, and, by an arrangement made apparently by his mother, he was boarded within the college under the special charge of the principal, John Rutherfurd. Had Napier followed the usual course his name would appear in the list of "Determinantes" for 1566, and of Masters of Arts for 1568; but no trace of it has been found, and the only conclusion to be drawn from its absence is that his residence at St. Salvator's was comparatively short. Principal Rutherfurd seems to have been a man of respectable attainments, but there can be little doubt that it was not at St. Andrews that Napier acquired his wide knowledge of classical literature or was set upon the path that led to his discoveries and inventions in the field of mathematics.

The influence on his future life of his residence at St. Andrews was, nevertheless, of the most far-reaching character; for it was then that he received an impetus to theological studies that formed throughout his life quite as great an attraction as mathematics in any of its branches.

Theology, of course, bulked largely in the discussions of the sixteenth century, and it seems to have had a fascination for Napier. Various references in his mathematical works can only be explained on the assumption that he could not divert his attention from theological studies sufficiently long to enable him to carry out cherished mathematical investigations. Whatever we may think of the ascendancy that James VI acquired over the Church in Scotland, I am inclined to believe it is James's victory over the Presbyterian party, to which Napier belonged, that compelled Napier to withdraw from the ecclesiastical field and devote himself to his mathematical studies.

It is almost certain, though there is no explicit documentary evidence, that Napier after leaving the university followed the advice of Adam Bothwell, and spent some years on the continent, studying probably at the University of Paris, and visiting the Netherlands and Italy. The extreme probability that, as a member of a noble family, he would be sent to pursue his studies abroad is confirmed by some interesting facts which are mentioned by Mark Napier in his introduction to the posthumous work "De Arte Logistica." Of Napier's travels or of the men under whom he studied or with whom he made acquaintance we have, however, no record; we know that he was in Scotland in 1571.

As the possessor of extensive estates it is fitting that Napier should have turned his attention to the improvement of agriculture. He took keen interest in his property, was inclined to insist upon what he thought to be his rights, but was at the same time eager to promote methods of tillage that offered prospects of better returns. He is said to have carried out careful experiments on "the gooding and manuring of all sorts of field land with common salts, whereby the same may bring forth in more abundance, both of grass and corn of all sorts, and far cheaper than by the common way of dunging used heretofore in Scotland."

Napier's inventiveness was not limited to the peaceful domain of mathematics, but showed itself in devising instruments of war. Mark Napier gives a *fac-simile* of a document preserved in the Bacon Collection in Lambeth Palace, in which John Napier describes some "Secret Inventions, profitable and necessary in these days for defence of this island and withstanding of strangers, enemies of God's truth and religion." The inventions consist of (1) a mirror for burning the enemies' ships at any distance, (2) a piece of artillery destroying everything round an arc of a circle, and (3) a round metal chariot so constructed that its occupants could move it rapidly and easily, while firing out through small holes in it. Sir Thomas Urquhart asserts that Napier did construct an engine which he tested on a large plain in Scotland "to the destruction of a great many herds of cattle and flocks of sheep, whereof some were distant from other half a mile on all sides, and some a whole mile." It would be hazardous, however, to make any assertion on the strength of Sir Thomas's evidence, and we know too little about these inventions to form any definite conception of them; but there is little doubt that Napier had quite decided mechanical skill.

Of Napier's claims to remembrance, however, the greatest is his invention of logarithms. It has often been remarked that the great discoveries and inventions have always come just when the time was ripe for them, and that if one man had not made the decisive step in advance another would have done so almost as soon. This statement is perhaps less accurate in regard to the invention of logarithms than in respect of many other discoveries; for, with one possible exception, there is no suggestion even that Napier has a rival. The exception is Jobst Bürgi, an ingenious Swiss watchmaker and mechanic. But Napier's "Canon Mirificus" was published six years before Bürgi's "Progress Tabulen"; Bürgi's Tables are very imperfect compared with Napier's; and there is every reason for believing that Napier had formed his conception of logarithms and begun their calculation quite as early as Bürgi—probably much earlier. Besides, Bürgi's work has not had the slightest influence, so far as can be traced, either on the theoretical or on the practical development of logarithms. Napier is therefore entitled to the full credit of an invention which ranks, in respect of its importance in the history of British science, as second only to Newton's "Principia."

The full title of Napier's work, published in 1614, is:—"Mirifici Logarithmorum Canonis Descriptio, Ejusque usus in utraque Trigonometria; ut etiam in omni Logistica Mathematica, Amplissimi, Facillimi, and expeditissimi explicatio. Authore ac Inventore, Ioanne Nepero, Barone Merchistonii, etc., Scoto. Edinburgi, Ex officina Andreae Hart Bibliopolae. CIↃ. DC. XIV."

This is printed on an ornamental title page. The work is a small sized quarto, containing 57 pages of explanatory matter, and 90 pages of tables.

An English translation of the "Descriptio" was made by Edward Wright and published in 1616, after the death of the translator, by his son, Samuel Wright. Napier, as stated in Samuel Wright's dedication to the "Right Honourable and Right Worshipful Company of Merchants of London trading to the East Indies," read the translation, and "after great pains taken therein gave approbation to it, both in substance and form." It is therefore perhaps not out of place to give Napier's own account of his invention as that is recorded in "The Author's Preface to the Admirable Table of Logarithms"; it is a slightly modified version of the Preface in the original Latin edition, the modification, however, referring merely to the general purpose and accuracy of the translation:

"Seeing there is nothing (right well-beloved Students of the Mathematics) that is so troublesome to mathematical practice, nor that doth more molest and hinder calculators, than the multiplications, divisions, square, and cubical extractions of great numbers, which besides the tedious expense of time are for the most part subject to many slippery errors, I began therefore to consider in my mind by what certain and ready art I might remove those hindrances. And having thought upon many things to this purpose, I found at length some excellent brief rules to be treated of (perhaps) hereafter. But amongst all, none more profitable than this which together with the hard and tedious multiplications, divisions, and extractions of roots, doth also cast away from the work itself even the very numbers themselves that are to be multiplied, divided, and resolved into roots, and putteth other numbers in their place which perform as much as they can do, only by addition and subtraction, division by two or division by three. Which secret invention, being (as all other good things are) so much the better as it shall be the more common, I thought good heretofore to set forth in Latin for the public use of mathematicians. But now some of our countrymen in this Island, well affected to these studies and the more public good, procured a most

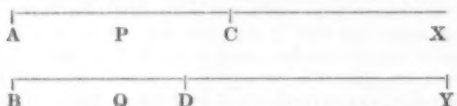
* Paper read before the Royal Philosophical Society of Glasgow, and published in the *Proceedings*.

learned mathematician to translate the same into our vulgar English tongue, who, after he had finished it, sent the copy of it to me to be seen and considered on by myself. I having most willingly and gladly done the same, find it to be most exact and precisely conformable to my mind and the original. Therefore it may please you who are inclined to these studies to receive it from me and the translator with as much good will as we recommend it unto you. Fare ye well."

I do not think one can state more clearly the purpose of logarithms; a more detailed statement necessarily calls for treatment that belongs to the region of mathematics. To those who are only acquainted with logarithms as they are explained in the modern elementary text-books the following points may be of interest:

1. Napier makes no use of a base. The conception of indices in the modern sense of fractional and negative indices was quite unknown in Napier's day and for long after. Algebra was as yet in far too crude a condition to provide a treatment of a logarithm as an index.

2. Napier's treatment is based on the comparison of the velocities of two moving points. Suppose one point P to set out from the point A and to move along the line AX with a uniform velocity V; then suppose another point Q to set out from B on the line BY, *of given*



length r, at the same time as P sets out from A and with the same velocity V as that of P on the line AX, but to move, not uniformly, but so that its velocity at any point, as D, is proportional to the distance DY from D to the end Y of the line BY. If now C is the point that P has reached, moving with the uniform velocity V, when Q, moving in the way described, has reached D, then the number which measures AC is the logarithm of the number which measures DY.

Napier had the needs of trigonometry primarily in view, and he usually speaks of BY (or r) as the whole sine and DY as a sine; it will be remembered that in Napier's day the sine was a line and not a ratio as with us.

4. When Q is at B the other point P is at A, so that the logarithm of the whole sine BY is zero. The logarithms of numbers less than BY, say log DY, are positive numbers; if Q were to the left of B then P would be to the left of A and AP would be negative, so that in Napier's system the logarithms of numbers greater than the whole sine are negative.

The circumstance that log 1 is not zero in Napier's system is very awkward. Napier was quite well aware of the disadvantages of taking the whole sine as the number whose logarithm was to be zero, and, as we shall see, afterward suggested the change to a system in which log 1 is zero. He had, however, some good reasons for his first choice, and it must be admitted that for the trigonometry he had chiefly in view the awkwardness is far less than it seems.

4. Napier next establishes the rule that if a is to b as c is to d, then

$$\log a - \log b = \log c - \log d,$$

and from this rule he readily establishes all the rules required for ordinary calculations.

The "Descriptio," besides stating and explaining the rules, gives many examples of the use of logarithms in trigonometrical calculations of a most varied kind; in the course of the work he proves some valuable theorems in spherical trigonometry. The tables give the sines, and the logarithms of the sines and of the tangents of all angles from 0 degree to 90 degrees at intervals of one minute.

It is pleasant that we can state that the value of Napier's invention was at once recognized. As has been mentioned, an English translation appeared in 1616; this translation contains, besides the author's own preface, one by Henry Briggs, geometry-reader (or, as we would say, professor of mathematics) at Gresham College, London. Some interesting statements are preserved of the enthusiasm with which Briggs welcomed Napier's invention. In a letter to Archbishop Usher, dated at Gresham House, March 10th, 1615, he writes: "Napper, lord of Markinston, hath set my head and hands a work with his new and admirable logarithms. I hope to see him this summer, if it please God, for I never saw a book which pleased me better or made me more wonder." Again, Dr. Thomas Smith in his life of Briggs, in the "Vitæ quorundam eruditissimorum et illustrium virorum," says of him when describing his enthusiasm over the "Canon Mirificus": "He cherished it as the apple of his eye; it was ever in his bosom or in his hand, or pressed to his heart, and, with greedy eyes and mind absorbed, he read it again and again. . . . . It was the theme of his praise in familiar conversation with his friends, and he expounded it to his students in the lecture room."

These expressions of Briggs are of special value to us at the present day, because Briggs was a mathematician of great eminence; his appreciation of Napier's work gives us some definite conception, both of the grievous nature of the burden that necessary calculations imposed *on the really competent computer*, and of the relief that the logarithms provided.

Briggs paid his anticipated visit to Napier in the summer of 1615, and there is an interesting story told to Ashmole by William Lilly, the astrologer, of his reception at Merchiston. "I will acquaint you," Lilly narrates in his "Life," "with one memorable story related unto me by John Marr, an excellent mathematician and geometrician whom I conceive you remember. He was servant to King James I and Charles I. When Merchiston first published his logarithms Mr. Briggs, then reader of the astronomy lectures at Gresham College in London, was so surprised with admiration of them that he could have no quietness in himself until he had seen that noble person whose only invention they were. He acquaints John Marr therewith who went into Scotland before Mr. Briggs purposely to be there when these two so learned persons should meet. Mr. Briggs appoints a certain day when to meet at Edinburgh; but, failing thereof, Merchiston was fearful he would not come. It happened one day as John Marr and the Lord Napier were speaking of Mr. Briggs, 'Oh! John,' said Merchiston, 'Mr. Briggs will not come now'; at the very instant one knocks at the gate, John Marr hasted down and it proved to be Mr. Briggs to his great contentment. He brings Mr. Briggs into my lord's chamber, where almost one quarter of an hour was spent, each beholding other with admiration, before one word was spoken. At last Mr. Briggs began, 'My Lord, I have undertaken this long journey purposely to see your person, and to know by what engine of wit or ingenuity you came first to think of this most excellent help unto astronomy, viz., the logarithms; but, my Lord, being by you found out, I wonder nobody else found it out before, when, now being known, it appears so easy.'"

Napier and Briggs must have been congenial spirits, for Briggs spent a month at Merchiston, returned for a second visit in the following summer, and intended to make a third visit in the next year; but Napier died before Briggs was free to set out for the north.

At the first visit Napier and Briggs discussed certain changes in the system of logarithms. In a letter to Napier before the first visit, Briggs had suggested that it would be more convenient, while the logarithm of the whole sine was still taken at zero, to take the logarithm of the tenth part of the sine as a power of 10, and he had actually begun the calculation of tables of his proposed system. Napier agreed that a change was desirable and stated that he had formerly wished to make a change; but that he had preferred to publish the tables already prepared, as he could not, on account of ill health and for other weighty reasons, undertake the construction of new tables. He proposed, however, a somewhat different system from that suggested by Briggs, namely, that zero should be the logarithm, not of the whole sine but of unity, while, as Briggs suggested, the logarithm of the tenth part of the sine should be a power of 10. Briggs at once admitted that Napier's method was decidedly the better, and he set about the calculation of tables on the new system, which is essentially the system of logarithms now in use.

In an "Admonition" printed on the last page of some (not of all) of the copies of the "Canon Mirificus," in a passage of the English translation, and in the dedication to the "Rabdologia," Napier refers to the change of system, but does not state explicitly the share Briggs had in it, though in the dedication he speaks in the heartiest terms of "that most learned man, Henry Briggs, public professor of geometry in London, my most beloved friend."

The copy of the "Canon Mirificus" in the Hunterian Museum of Glasgow University has the "Admonitio." On the title page is written, "Nathan Wrighte of Englefield." Can this be a relative of Edward Wright?

Unfortunately, Dr. Charles Hutton, in the excellent history of logarithms prefixed to the early editions of his Mathematical Tables, gives a version of this story that charges Napier with the intention of belittling Briggs's services, and of allowing no one but himself any credit in the improvement of the original system. It is very difficult to understand how Hutton could come to write as he did, especially as he has no justification in a single recorded word of Briggs himself. Briggs never to his last day spoke of Napier except in terms of the warmest affection, and never showed the least trace of a feeling that Napier had withheld from him any recognition such as Hutton demands. The friendship of Napier and Briggs was almost ideal in its sincerity and warmth, and Hutton's allegations are much to be regretted, occurring as they do in a work that has a deserved reputation for its general accuracy and wide knowledge of mathematical history.

The "Canon Mirificus" gave no account of the method by which the logarithms had been calculated. Napier there states that he prefers to show their use "that the use and profit of the thing being first conceived, the rest may please the more, being set forth hereafter, or else displease the less, being buried in silence. For I expect the judgment and censure of learned men hereupon, before the rest, rashly published, be exposed to the detraction of the envious." Napier did not himself publish any account of his method of calculating logarithms, but in 1619, after his death, his second work on logarithms, "Mirifici Logarithmorum Canonis Constructio," came from the press of Andrew Hart under the editorship of Briggs, and with a preface by Robert Napier, the second son of his second marriage. In the preface Robert Napier notes that in the book logarithms are called "artificial numbers" because his father "had this treatise beside him composed for several years before he invented the word Logarithms." It is interesting to observe the cordiality of his reference to Briggs; "the whole burden of the business seems to have fallen on the shoulders of the most learned Briggs, as if it were his peculiar destiny to adorn this Sparta."

Robert Napier appears to have been his father's scientific executor; among his papers was found a copy of a treatise by his father on Arithmetic and Algebra which bears the title, in Robert Napier's handwriting: "The Baron of Merchiston his Booke of Arithmeticke and Algebra. For Mr. Henrie Briggs, Professor of Geometrie at Oxfoorde." Whether this treatise was ever sent to Briggs is not known; it was edited for the Bannatyne Club by Mark Napier, and published in 1839 under the title "De Arte Logistica."

"The whole burden" of calculating the new system of logarithms did in a very real sense fall on the shoulders of Briggs, and he devoted to the work conspicuous ability as well as unflagging zeal. Although this is not the occasion for an appreciation of Briggs, it may not be out of place to mention that the Simson collection in our University Library possesses a copy of Briggs's "Arithmetica Logarithmica" of 1624 with this inscription on the first blank leaf: "Hunc mihi donavit Henricus Briggius Anno 1625"; on the title page is the name Rob: Naper, and below this name is written in Simson's well-known hand

Rob: Simson, M.DCCXXXIII.

I do not know how this copy came into Simson's possession, but it is gratifying to have this tangible testimony to the good feeling that subsisted between Briggs and Napier's son.

The earliest publication of logarithms on the continent was in 1617, when Benjamin Ursinus included in his "Cursus Mathematicus Practicus" Napier's canon of 1614, shortened two places. It was through this book that Kepler was aroused to the importance of Napier's discovery, though he had previously seen but not read the "Canon Mirificus." His first hasty glance at the "Canon Mirificus" only led him to express himself in somewhat disparaging terms of the author—*Scotus Baro cujus nomen mihi excidit;* but when he had once studied the new method his enthusiasm was akin to that of Briggs. The dedication of his "Ephemeris" for 1620 consists of a letter to Napier dated from Lintz on the Danube, July 28th, 1619. He was not aware that Napier had been then dead for more than two years. In the letter he states that he had used Napier's logarithms in the construction of this "Ephemeris" and therefore, of right, dedicated it to the "illustrious Baron." In 1624 Kepler published a table of Napierean logarithms with certain modifications and additions. It is perhaps worth noting that by comparing a letter from Kepler to Peter Crüger with a statement made by Anthony Wood in the "Athenæ Oxonienses" about a visit of Dr. Craig, son of the feudist Sir Thomas Craig, one may reasonably infer that Napier was on the track of his logarithms as early as 1594.

This is not the occasion on which to pursue the history of Napier's logarithms. The credit of the invention is justly due to Napier and to Napier alone, but it would be very unjust to forget or to minimize the unique share that Briggs took in the promulgation of the logarithms. The tables in use at the present day are not those of Napier, but those of Briggs, supplemented by those of Adrian Vlacq. Briggs seems to have been a man of the finest type, learned, able, and unselfish; it is only the merest justice to rank him alongside Napier in the history of the invention and calculation of logarithms.

Napier's conception of the logarithm cannot fail to suggest to the student of mathematics Newton's treatment of the fluxional calculus; not that Newton borrowed from Napier, but that the fundamental ideas of both are so much alike. The great generality of Napier's conception has been more clearly understood in recent years, and there is a strong tendency, at least so far as the advanced stages of mathematical study are concerned, to return to a definition of the logarithm that is equivalent to that of Napier.

In the course of his illustrations of the uses of logarithms Napier had frequent occasion to discuss trigonometric theorems, and the latest historian of trigonometry, Dr. A. von Braunmühl, estimates Napier's work in this connection to be of the highest value. Napier, he considers, completely reorganized spherical trigonometry and enormously simplified the treatment of nearly all the trigonometrical formulæ.

Another achievement of Napier should be mentioned here, namely that, though he did not introduce decimal fractions, he did introduce the decimal point, and showed, in the "Constructio," the perfect simplicity and generality that attended its use. The decimal point is one of those simple devices that we take for granted but that needed a genius to invent; many years elapsed before its use became quite general.

John Napier died on the 3rd of April, 1617, and was buried in the church of St. Cuthbert, Edinburgh. It is often stated that he was buried in St. Giles's, but it may now be held as established that it was in the church of St. Cuthbert—the church in which he was an elder—that his body was laid.

David Hume ("History," vol. vii, p. 44) casually refers to Napier as "the person to whom the title of a GREAT MAN is more justly due than to any other whom his country ever produced." Even though this judgment be challenged—and it is hard to decide who is most worthy of such an honorable title—every competent critic will concede that Napier's influence on the development of mathematics and its manifold applications in modern life was profound and far reaching. A man of the highest culture, well versed in classical and theological learning, he was not exempt from the failings that are characteristic of the age in which he lived; in these he shows his kinship with common folk, and elicits our sympathy rather than our censure. But he was a man of pure and simple life, a sincere patriot, a genuine lover of spiritual religion and not merely an exponent of the particular forms it assumed in the confused theology of his day. In originality of conception and depth of insight he is one of the small band of mathematical thinkers, represented by Archimedes in antiquity and by Newton in more modern times, whose genius consolidated the labors of their predecessors and laid down the lines of future advance.

Though Napier's work was an essential condition of modern industrial development and reacted powerfully on modern thought, his name has little or no place in current text-books of Scottish history. Volumes have been written recording in minute detail the most petty squabbles of the sovereigns whose reign he adorned but never mentioning his name. Yet he is honored wherever science is taught, and he is a man whom every Scotchman should be proud to claim as a compatriot.

Some Further Experiments With Liquid Drops and Globules

Life-like Properties of Inert Matter

By Charles R. Darling, A.R.C.Sc.I., F.I.C.

In the issues of the SCIENTIFIC AMERICAN SUPPLEMENT of April 12th and May 31st, 1913, the author described a number of new experiments with liquids approximating in density to water, with special reference to the formation of spheres, drops, and columns, and the movements of globules on the surface of water. The present article, which is reproduced from our English contemporary, *Knowledge*, is intended to supplement those which have previously appeared and will be devoted to a description of some further experiments with the same class of liquids.

WATER SPHERES IN ANILINE SKINS.

At first sight it might appear a difficult operation to inclose one liquid in the skin of another; nothing, however, could be simpler. A layer of aniline is placed at the bottom of a beaker, and covered with water to a depth of about two inches. A glass tube, of bore about one eighth of an inch, open at both ends, is then inserted in the water, and lowered until the end is submerged in the aniline. (As the tube is open, water will enter it on immersion, so as to stand at the same level as that in the beaker.) On lifting the tube out of the aniline a skin of this liquid adheres to the end; and on raising it further this skin is inflated by the water in the tube, which sinks so as to maintain the common level. In this manner the film of aniline is distended

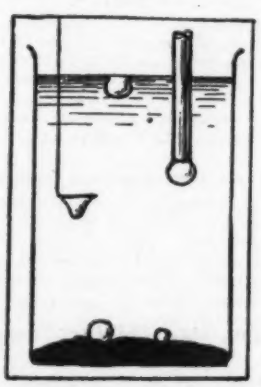


Fig. 1.—Aniline skins enclosing water.

by water, just as a soap-film is blown into a bubble with air. In removing the tube entirely from the water the composite spheres remain clinging to the surface, or may fall through the water to the bottom of the beaker (see Fig. 1). If a ring of wire, about three eighths of an inch in diameter, be dipped beneath the aniline and then withdrawn a flat film will adhere, which may be stretched into the familiar shape of a falling drop by lifting the wire suddenly. Many interesting experiments are possible with these films, which are obtained more readily after the aniline has been in contact with the water for some days.

THE "DIVING" DROP.

This experiment illustrates in a striking manner the force with which the surface of a liquid is restored to its normal shape after undergoing distortion. A quantity of dimethyl-aniline is poured onto water to a depth of three quarters of an inch, and a sphere of the liquid, encased in a water skin, formed as described in the previous experiment (see Fig. 2, A). On lifting the tube out of the liquid the sphere falls from the end, and rests on the joining-surface (see Fig. 2, B), where it remains for a few seconds, when it suddenly bursts through the interface, and is projected with some violence downward (see Fig. 2, C), the skin of water having now disappeared. The drop—now composed entirely of dimethyl-aniline—then rises to the top of the water, breaks through the surface, and merges into the liquid above.

This curious behavior on the part of the compound sphere admits of a simple explanation. After resting for a time on the interface the under-part of its skin becomes continuous with the water below, with the result that the shape of the surface joining the two

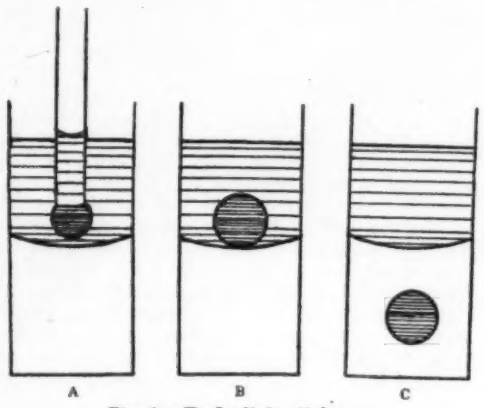


Fig. 2.—The "diving" drop.

liquids is changed, the sides being now connected to the water-skin forming the upper part of the drop. This is an unstable shape for a stretched surface, which always tends to occupy the minimum area; and hence the skin assumes its normal shape, and with sufficient force to cause the drop beneath it to dive into the water to some depth, although dimethyl-aniline is lighter than water, and tends to float. On the sphere rising and breaking through the interface a similar action, in the

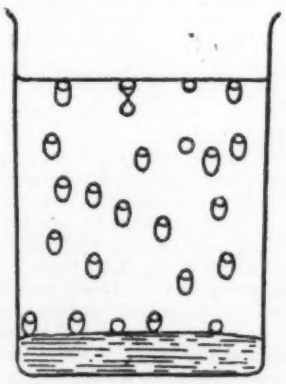


Fig. 3.—The "dancing" drop.

reverse direction, takes place, but cannot be seen owing to the sphere losing its identity on entering its own liquid.

"Diving" drops can be obtained by using ordinary paraffin oil instead of dimethyl-aniline; the effect, however, is not so well marked.

THE "DANCING" DROPS.

When a volatile liquid is heated beneath a layer of water the bubbles of vapor, on leaving the joining-surface and entering the water, tend to carry with them a portion of the liquid below. This may be seen on heating a layer of chloroform about half an inch deep, covered by water to a depth of about three inches. The action, however, is much more striking if *monobrom-benzene* be used, as this liquid possesses a higher boiling-point than chloroform. On heating the liquid the vapor bubbles enter the water loaded with a drop of liquid, the amount detached being such as to make the density of the combined vapor and liquid drops about equal to that of water. On rising the drops enter a colder layer of water, which causes the vapor to contract and partially condense, with the result that the drops sink. On reaching the warmer region below, however, the lifting power is restored, and the drops rise again. The appearance of the drops is shown in Fig. 3, but the chief interest of the experiment lies in the novelty of the movements. Some reach the surface at once, and there discharge the vapor, when the attached liquid falls; others dance up and down with great rapidity; while others, the densities of which are nicely balanced with that of the water, move slowly upward or downward. This simple experiment is at once interesting and instructive, and is one in which actual observation conveys far more than a mere description.

THE "EXPANDING" GLOBULE.

A globule at rest on the surface of water is maintained in equilibrium by the operation of three tensions,

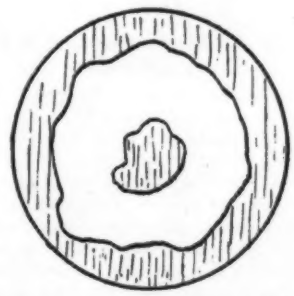


Fig. 4.—The "expanding" globule.

viz., water-air, liquid-air, and water-liquid, or interfacial. Any alteration in these tensions will disturb the equilibrium and cause the globule to alter in shape. This is shown in a striking manner by floating a globule of aniline on water and dropping into it a small quantity of quinoline, when the globule will be observed to expand violently in all directions, leaving a hole in the center (see Fig. 4). This action is even more intense if a drop of quinoline be placed on a globule of light lubricating oil, when it will be observed that the quinoline sinks through the globule, without causing any disturbance, until it breaks through the junction of the oil and water, when the globule spreads out with such force as to be broken into several portions. This phenomenon is therefore due to an alteration in the interfacial tension, which now offers less opposition to the pull of the water-air tension on the globule, and hence spreading occurs.

THE "DEVOURING" GLOBULE.

When globules of different liquids are floating on the same water surface a tendency to join together is sometimes noticed, and the same applies to separate globules of the same liquid. This tendency to coalesce with other globules is shown in a marked degree by dimethyl-

aniline, and may be utilized so as to give the novel appearance of one globule feeding on another. To show this effect to best advantage, a small quantity of orthotoluidine is poured onto a clean water surface, when it breaks up into a number of active globules. A large globule of dimethyl-aniline is then formed on the surface, which at once proceeds to feast upon the orthotoluidine. The procedure is shown in Fig. 5, which represents (1) the initial stage; (2) the large globule of dimethyl-aniline sending out a protuberance in the

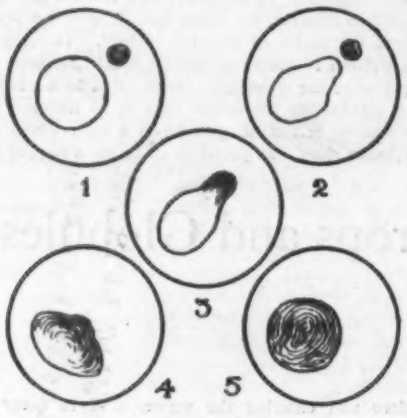


Fig. 5.—The "devouring" globule.

direction of the small one; (3) the small globule incorporated; (4) the protuberance withdrawn, causing a recoil which spreads the large globule laterally; and (5) the globule restored to its proper shape, showing streaks due to the orthotoluidine not being perfectly mixed—an operation which takes a short time, after which the globule becomes clear again. The process is then repeated, one after another of the orthotoluidine globules being absorbed until the surface has been cleared, when the "devourer" comes to rest in the center of the surface. It is amusing to observe how the small globules sometimes retreat, as if trying to avoid capture, only to be pursued and made to share the common fate. The movements may be seen to better advantage when the surface is magnified by lantern projection, and resemble in a striking manner certain processes associated with life—such, for example, as a white blood-corpuscle (phagocyte) feeding on microbes. And it is interesting to note in this connection that some of the other movements of globules described by the author in previous issues of the SCIENTIFIC AMERICAN SUPPLEMENT show analogies to the movements of the lower organisms; for example, the pulsation of aniline globules and the motion of translation and subdivision of orthotoluidine; all of which only proves, however, that certain phenomena, usually supposed to be inseparable from life, may be produced with inert substances.

The Price of Labor Expressed in Terms of Food Fuel*

As man is a fuel-consuming machine, it requires no argument to emphasize the importance of knowledge concerning the food-fuel which he needs. It matters little whether instinct is an unerring guide in providing a suitable supply of nutriment for the individual. Unless food is available at a cost within the reach of those concerned, the possibility of inadequate maintenance at once arises. The question of the under-nutrition of the masses or the under-feeding of any group in society, whether it be school children, the indigent sick or the poorest laborers in the community, cannot be solved permanently before the actual nutritive needs of all of these classes are ascertained on an indisputable scientific basis. Only then is it possible to determine if the failure to obtain adequate nourishment is due, in each case, to poverty, or to the lack of suitable food-supplies or to ignorance and perverted judgment in the purchase of the day's ration.

For this reason, various "standards" have been proposed by physiologists and chemists for daily dietaries of persons of differing age, sex and occupation, and in different conditions of life. In general, these estimates have been based on two distinct methods of ascertaining the suitability of a ration. By the one, the quantities of food actually consumed by individuals or known groups of persons have been noted. The other method consists in determining, by special metabolism experiments, the actual physiologic demand for food. This furnishes information concerning the needs of man in maintaining a nutritive equilibrium under selected conditions of activity rather than what he would eat if given the freedom of choice. This method, being the more laborious and difficult mode of investigating dietary needs, has hitherto been employed less frequently in experimental inquiry than has the statistical method.

* Reproduced from the *Journal* of the American Medical Association.

On the basis of the former procedure, in which the proportions of foodstuffs assumed to be needed are inferred empirically from those consumed in observed cases, nearly all of the widely quoted dietary standards have been established. Any one who hopes to interpret or employ them rationally must bear certain fundamental principles of nutrition in mind. The requirements of the body in terms of food-fuel or energy depend on the way in which food is used to build the organism and repair its waste, and above all on its heat- and power-yielding quality, particularly through the activity of the musculature. Bearing these facts in mind, it is obvious that the size of an individual is one of the factors which determine the need of food. If vigorous growth is still in progress, the demand of nutrients for new tissue construction may become noteworthy. Chief, however, stand the variations of demand caused by the unlike expenditure of energy in different occupations. The sedentary bookkeeper or seamstress requires a far smaller supply of energy than the wood-chopper or the washerwoman. It is a customary assumption that, because of her smaller average stature and lesser muscular performance, a woman requires on the average eight tenths as much food as a man for corresponding muscular activity. It has also been assumed that children of different ages consume from three tenths to eight tenths as much as the man of the family. Such generalizations have become necessary whenever the food habits of people have been investigated by the observation of food purchase or consumption in entire families.

We shall not go far amiss if we express the current dietary standards, so far as they are based on the preceding mode of estimating them for conditions prevailing in the United States, in terms of the results compiled by Dr. Langworthy of the United States Department of Agriculture, as follows:

Occupation of Head of Family.	Fuel Value of Food per Man per Day, in Calories.
Man at very hard work	6,000
Farmers, mechanics, etc	3,425
Business men, students	3,285
Inmates of institutions, little or no work	2,600
Very poor persons, usually out of work	2,100

Without denying, in any way, the importance and great value of such indirect data, one may frankly designate them as rather inexact. For this reason it is still desirable to check up their indications, whenever possible, by direct measurements of the energy transformations. Numerous results already collected by this method of investigation have given no occasion to question the general validity of the "standards" set by the less accurate statistical method. The latest of such metabolism studies is of particular interest because it was conducted under the conditions of work that represent in some adequate way the daily muscular performances of the persons concerned.[1] The experiments were conducted in the large respiration apparatus of the physiologic institute at the University of Helsingfors in Finland, the carbon dioxid output of the subjects being determined during periods of rest and characteristic activity, and calculated into terms of energy consumed. Making an allowance of 10 per cent for the alimentary waste of food, the gross results were as follows:

Men.	Calories per Day.
Tailor	2,600–2,800
Bookbinder	3,000
Shoemaker	3,100
Metal-worker	3,400–3,500
Painter	3,500–3,600
Cabinetmaker	3,500–3,600
Stone-cutter	4,700–5,200
Wood-cutter	5,500–6,000
Women.	
Seamstress (by hand)	2,000
Seamstress (sewing machine)	2,100–2,300
Bookbinder	2,100–2,300
Housemaid	2,500–3,200
Washerwoman	2,900–3,700

These interesting figures not only give an impressive confirmation of the energy standard derived by less direct methods of investigation, but also bring into immediate, clear relief the great differences that the various trades and occupations entail. Such facts need to be taken into consideration in institutions in which the inmates are assigned to work as unlike as bookkeeping or sewing on the one hand, and woodchopping or other forms of hard manual labor on the other. Such figures show the obvious physiologic injustice of doling out equal portions of the same ration to all of these persons, especially when free choice is restricted or practically impossible. Furthermore, it should be noted that the data of the Finnish physiologists are based on an eight-hour working day. Any lengthening of this period must affect the expenditure here represented.

It is impossible to determine from the cursory studies that have been made whether the scale of living or "standard of life" is actually much higher here, as has been asserted by some, than it is in Europe. One American authority, the late Prof. Atwater, frankly believed that, considering the body as a machine, the American workingman is more strongly built and has a larger fuel supply than his European brother. While it is not absolutely proved, it seems in the highest degree probable that the higher standard of living, the better nutrition, the large product of labor, and the higher wages go together. The justification for any propaganda in favor of more liberal standards for dietaries rests in a measure on the truth of this belief. And, speaking aside for the moment, a glance at the figures which we have quoted shows that the proverbial advice to "mind one's business and saw wood" entails no mediocre performance in terms of calories per day.

[1] Becker, G., and Hämäläinen, J. W.: Untersuchungen über die Kohlensäureabgabe bei gewerblicher Arbeit, Skandin. Arch. f. Physiol., 1914, xxxi, 198.

The Flora of Guam has recently been studied by R. C. McGregor, of the Philippine Bureau of Science, who, in addition to the specimens which he took back to Manila, presented the Guam agricultural experiment station with an herbarium representing the results of his collections in the island. One genus and about forty species new to science are included in the collection.

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